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Helicopter Physical and Performance Data

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16. Abstract

A determination of physical and performance data for eight civil helicopters was made. The helicopters used in the study were chosen to exhibit a wide range of characteristics representative of the current civil fleet. Flight manual data as well as certification, flight test, and computer generated performance data were used to complete the study. Approach and departure profiles were developed for several gross weights and ambient conditions and translated into graphs. A menu-driven database was designed to provide easy access to the data.

The airspace required for approaches is dependent upon pilot skill and desired approach slope. Pilots can fly approaches steeper than the current standard 8:1 surface if required though pilot workload tends to increase and comfort levels tend to decrease.

The airspace required for departures is a function of aircraft performance and ambient conditions. Three types of departure procedures were studied: "optimum" with respect to airspace, manufacturer's recommended, and Category A. Results show that minimum VFR heliport airspace requirements are dictated by departure profiles. Current flight manual departure procedures often break the 8:1 surface described in Heliport Design, Advisory Circular 150/5390-2. Implications are considered in detail in Heliport VFR Airspace Based on Helicopter Performance, DOT/FAA/RD-90/4.

This is one of a series of five reports that addresses helicopter performance profiles and their relationship to the VFR protected imaginary surfaces of approaches and departures at heliports. The other four are:

1) Heliport VFR Airspace Design Based on Helicopter Performance, DOT/FAA/RD-90/4.
2) Operational Survey - VFR Heliport Approaches and Departures, DOT/FAA/RD-90-5
3) Rotorcraft Acceleration and Climb Performance Model, DOT/FAA/RD-90-6, and
4) Helicopter Rejected Takeoff Airspace Requirements, DOT/FAA/RD-90/7.

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INTRODUCTION

Current FAA criteria for visual meteorological conditions (VMC) heliport takeoff/landing surfaces and approach/departure airspace is based on operational judgment. This report documents the methodology, assumptions, analyses, and discussion of a study conducted by Systems Control Technology, Inc. to determine approach and departure performance of eight civil helicopters. These eight helicopters were chosen as a representative sample of the current civil fleet. The conclusions drawn as a result of this study are discussed in "Heliport VFR Airspace Based on Helicopter Performance," DOT/FAA/RD-90/4. The entirety of these analyses will be considered to determine if current FAA VMC requirements for heliport airspace and real estate should be modified. Airspace requirements related to rejected takeoff and one engine inoperative (OEI) capability for heliports intended to support Category A operations are discussed in "Helicopter Rejected Takeoff Airspace Requirements," DOT/FAA/RD-90/7.

METHODOLOGY

The objective of the study was to assemble and generate helicopter physical and performance data, traceable to flight manuals and manufacturer data, to be used to make recommendations regarding changes to heliport airspace and real estate requirements. The product of the study is a data base of physical and performance data stored on a floppy disk. The data was generated to support the computation of helicopter approach and departure profiles. The data base provides the FAA with the capability to test operational VMC takeoff and landing scenarios under a variety of helicopter loading and ambient conditions. This chapter explains the methodology used to create this product.

A flowchart of the methodology used to achieve the required product is shown in figure 1. After reviewing previous studies of heliport real estate and airspace requirements, a list of helicopters for the study was chosen. Source data for each helicopter was gathered and reviewed. From these source data a physical data base of the helicopters' characteristics was developed. Physical and performance data were provided to a subcontractor to generate more detailed departure performance data using a helicopter sizing and performance computer program. Departure procedures were applied to this computer-generated performance data to produce departure profiles. Approach profiles were derived from flight manual approach procedures and results of VMC approach testing performed by the FAA Technical Center and NASA. A menu driven program was written to provide the user easy access to the physical, approach and departure profiles data, and all were stored on a floppy disk. Graphs of the profiles were generated separately for this report.

SCT reviewed a previous study of heliport airspace and real estate requirements that was generated for the FAA in 1980 by PACER Systems, Inc. The study cited an earlier performance analysis of twelve helicopters and generalized the results to determine heliport airspace and real estate requirements. As a result of this generalization all traceability to individual helicopter flight manuals was erased. Two actions were recommended in the report with regard to VFR airspace and real estate requirements; that current VFR obstacle surfaces for ground

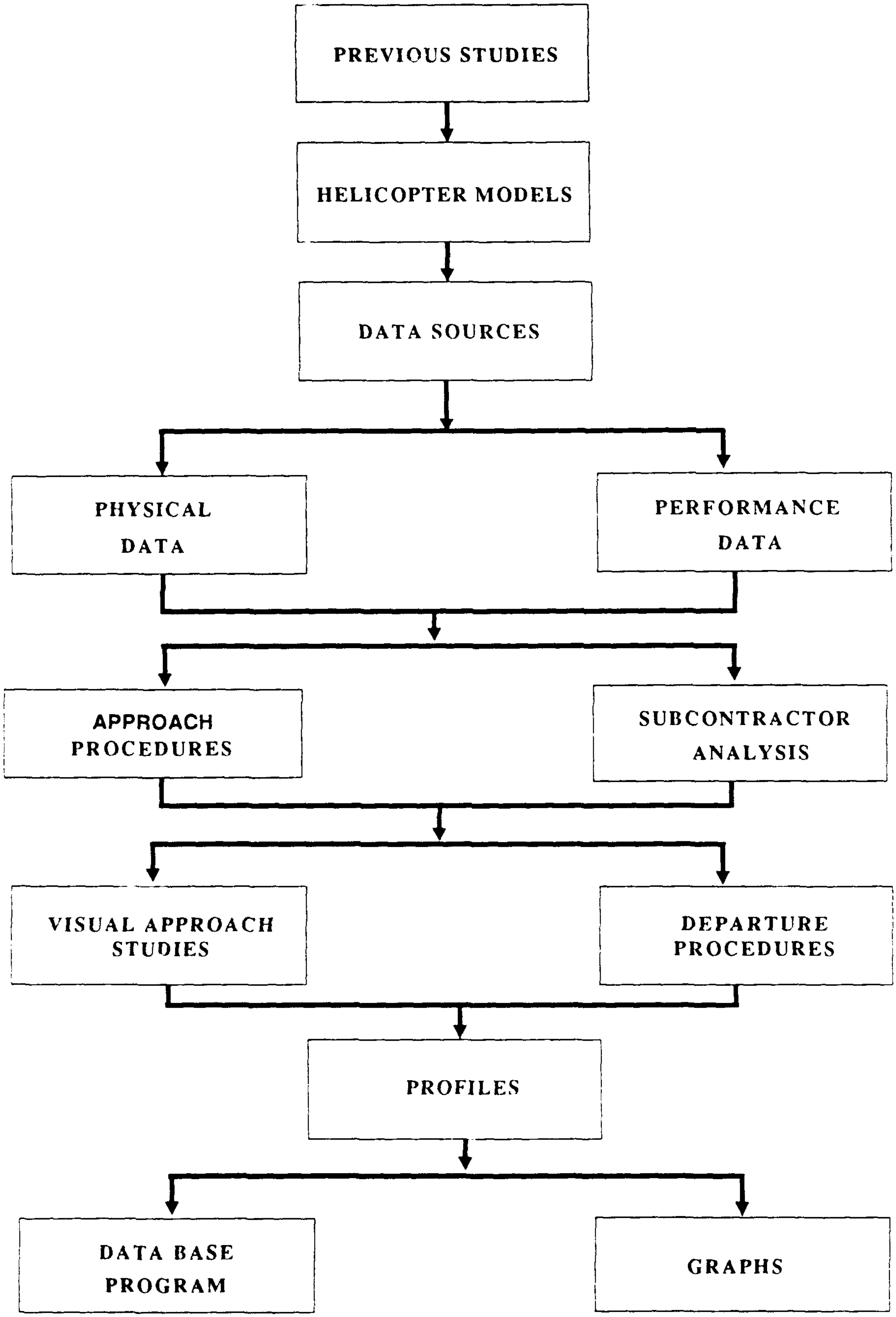


FIGURE 1. METHODOLOGY FLOW DIAGRAM

level heliports be applied to both fixed and mobile offshore helicopter landing facilities, and to amend rotorcraft flight manual standards to include performance charts to determine vertical climb capability, best angle of climb airspeed, hover performance and acceleration distance to reach selected airspeeds at various combinations of weight, altitude and temperature. As a consequence of choosing not to implement the recommended changes to the flight manual standards, the report suggested that the FAA require additional real estate and airspace to accommodate the execution of a level acceleration through effective translational lift prior to the beginning of a climb for all helicopters. These recommendations were not well-received by the rotorcraft industry for a variety of operational and economic reasons. Primary among these was that historically, safe operations had been conducted using the current real estate and airspace requirements so that the imposition of additional requirements was thought to not be warranted.

The intent of this study was to analyze the performance of eight helicopters and retain traceability to their respective flight manuals. Eight helicopters were chosen for the study on the basis that they represent a substantial portion of the current civil fleet and cover a wide range of gross weights, engine types and instrument equipage. The table that follows illustrates these qualifying characteristics of the eight helicopters chosen for the study. Percent fleet figures were determined by the number of aircraft titled in the U.S. as of October 1987 and were obtained from the 1988 Helicopter Annual published by Helicopter Association International. The specific variation of each helicopter used in the study is listed.

HELICOPTER	GROSS WEIGHT	ENGINE	NO.	% FLEET	VFR/IFR
F 28F	2600	LYC HIO-360-F1AD	1	4	VFR
MD 369/500	3000	ALL 250-C20B	1	8	VFR
B 206 A/B	3200	ALL 250-C20J	1	17	VFR
AS 355	5071	ALL 250-C20F	2	2	VFR/IFR
MBB BO 105	5512	ALL 250-C20B	2	2	VFR
S 76	10500	ALL 250-C30S	2	2	VFR/IFR
AS 332	18959	TMECA MAKILA IA	2	.1	VFR/IFR
BV 234	48500	LYC AL5512	2	.1	VFR/IFR

TOTAL % FLEET 35.2

HELICOPTER MODEL	VARIATION	NAME
F 28F	F 28F	Enstrom Falcon
MD 369/500	MD 500E	McDonnell Douglas 500E
B 206 A/B	B 206B III	Bell Jet Ranger III
AS 355	AS 355F	Aerospatiale Twin Star
MBB BO 105	MBB BO 105 CBS	Messerschmitt-Bolkow-Blohm GmbH Twin Jet II
S 76	S 76A	Sikorsky Spirit
AS 332	AS 332C	Aerospatiale Super Puma
BV 234	BV 234 LR	Boeing Vertol Passenger Chinook

SOURCE DATA

Based on the completeness of military helicopter flight manuals reviewed by SCT for previous studies it was originally planned that all the information needed to conduct this study would be available in the civil helicopter flight manuals. A request was made to the FAA coordinator at each manufacturer's facility for a flight manual. Enstrom, Bell, and Aerospatiale each sent a master copy of their respective helicopter flight manual(s). Complete flight manuals were not received from all manufacturers, but all manufacturers were extremely helpful in providing sections of their flight manuals and relevant information. After intensive review of each flight manual and flight manual sections provided, it was apparent that additional performance and physical data were needed to perform this study. Most of the additional information was requested and obtained from the manufacturers but some were available from the FAA and existing documentation.

The Official Helicopter Blue Book published by Helicopter Financial Services Inc. contains a variety of information on rotorcraft. This guide was consulted when other sources failed to yield specific information.

DATA TRACEABILITY

Physical data for the eight helicopters of this study are housed within the physical data base file stored on the floppy disk delivered as part of this task to the FAA. This data base file is presented as table 1. A description of each physical data category of the data base file in order of presentation follows. The corresponding category titles shown in table 1 are listed in parentheses. Not applicable is represented by N/A while a dash indicates the data was not available.

Name (NAME). The name of the aircraft is abbreviated. The eight aircraft are the Enstrom F 28F, McDonnell Douglas 500E, Bell 206B III, Aerospatiale 355F, MBB BO105 CBS, Sikorsky S 76A, Aerospatiale 332C and Boeing Vertol 234 LR.

Engine Manufacturer (ENG MANU). Each engine manufacturer is listed. Lycoming, Allison and Turbomeca are represented.

Engine Number (ENG NO). The number of engines per aircraft. Three single engine and five twin engine aircraft are used for this study.

Engine Model (ENG MODEL). The manufacturer's engine model number.

Takeoff Power Available (PR TO). The takeoff power available per engine for each aircraft in terms of horsepower.

Maximum Continuous Power Available (PR MAX). The power available for maximum continuous operation per engine in units of horsepower.

Single Engine 30 Minute Power Available (PR 130M). For twin engine aircraft, the 30 minute power available rating for a single engine after the power loss of the other engine occurs is shown in terms of horsepower.

TABLE 1. PHYSICAL DATA BASE FILE

RECORD#	NAME	ENG_MANU	ENG_NO	ENG_MODEL	PR_TO	PR_MAX	PR_130M	TR_TO	TR_MAX	TR_LENG	RS_BLM	RS_BLT	RS_RPMM	RS_RPMT	RS_DIAM	RS_DIAT	RS_CHORM	RS_CHORT	RS_DAREAM	RS_DAREAT
1	F 28F	LYCOMING	1	HIO-360-F1AD	225	225	N/A	225	225	N/A	3	2	350	2504	32.00	4.78	0.79	0.37	804.25	17.95
2	MD 500E	ALLISON	1	250-C20B	420	370	N/A	375	350	N/A	5	4	487	2188	26.41	4.60	0.56	0.44	547.81	16.62
3	B 206B III	ALLISON	1	250-C20J	420	370	N/A	317	270	N/A	2	2	394	2550	33.30	5.42	1.08	0.44	873.00	23.10
4	AS 355F	ALLISON	2	250-C20F	420	370	-	678	678	-	3	2	394	2088	35.07	6.10	1.15	0.61	966.12	29.28
5	BO 105 CBS	ALLISON	2	250-C20B	420	400	-	690	690	380	4	2	424	2220	32.28	6.23	0.89	0.59	818.56	30.57
6	S 76A	ALLISON	2	250-C30S	650	557	630	1300	1300	700	4	4	244	609	44.00	8.00	1.28	0.53	1520.53	50.27
7	AS 332C	TURBOMECA	2	MAKILA IA	1662	1515	1662	2997	-	2079	4	5	265	1279	51.17	10.00	2.00	0.67	2057.27	78.70
8	BV 234 LR	LYCOMING	2	AL5512	4075	2975	4355	6750	6480	4600	3	3	225	225	60.00	60.00	2.67	2.67	5652.00	5652.00

REPORT#	NAME	RS_DISCLD	RS_PWRLD	EX_LFUSE	EX_TTURN	EX_BTURN	EX_WFUSE	EX_WIPT	EX_GETP	EX_WLGP	EX_GELG	EX_HURHT	EX_TARCHT	EX_GFUSE	AC_SEAT	AC_DENS	WT_GROSS	WT_EMPTY	WT_FUEL
1	F 28F	3.23	11.56	25.73	28.08	30.30	5.25	7.33	SKID	7.33	8.00	9.00	7.81	1.58	3	3	2600	1550	810
2	MD 500E	5.48	7.14	23.20	26.50	30.80	4.60	6.50	SKID	6.50	8.28	8.70	8.20	1.30	5	7	3000	1455	1116
3	B 206B III	3.67	7.62	31.20	31.20	39.10	4.33	6.40	SKID	6.40	8.02	9.50	7.56	1.00	5	5	3200	1635	955
4	AS 355F	5.25	6.04	35.79	35.79	42.62	5.90	8.30	SKID	6.89	-	9.65	8.00	1.27	5	6	5071	2900	1119
5	BO 105 CBS	6.73	6.56	28.90	0.00	38.91	5.18	8.30	SKID	8.30	-	9.83	12.47	1.05	5	6	5291	2694	1793
6	S 76A	6.77	7.92	43.37	45.20	52.50	7.00	10.00	WHEEL/TRI-SF, SA	8.46	16.42	13.50	14.48	1.00	14	14	10500	5930	2687
7	AS 332C	9.22	5.70	48.43	50.92	61.33	6.56	11.08	WHEEL/TRI-DF, SA	9.83	14.67	15.08	16.14	1.42	19	22	18959	9259	6946
8	BV 234 LR	4.29	7.18	52.08	N/A	99.00	15.67	15.67	WHEEL/QUAD-DF,SA	11.71	25.83	18.65	N/A	-	46	46	48500	25900	8509

REPORT#	NAME	WT_LOAD	FUE_TANK	RAN_MAX	RAN_ENDCR	PER_SC	PER_SC1STD	PER_SC1HOT	PER_HIGE	PER_HIGEHT	PER_HOGE	PER_HOGEHT	PER_ROCOB	PER_ROCVE	PER_ROC1	PER_VNE	CERT_VFR	CERT_IVR
1	F 28F	1000	40	228	3.5	9000	N/A	N/A	7700	2200	0	0	1450	0	N/A	74	12/30/80	N/A
2	MD 500E	2000	64	261	2.8	15000	N/A	N/A	8400	5800	7200	4400	1716	910	N/A	152	11/23/82	N/A
3	B 206B III	1500	91	369	3.2	13500	N/A	N/A	12800	10200	8800	3800	1280	304	N/A	122	07/01/77	N/A
4	AS 355F	2304	193	391	4.7	13120	2790	-	9400	6750	7800	5300	1600	848	420	150	11/20/81	08/06/82
5	BO 105 CBS	1984	153	310	3.5	17000	2700	0	7500	5400	5200	2800	1510	560	100	145	07/25/77	N/A
6	S 76A	3300	281	404	3.5	14167	4300	0	2400	0	1200	0	1600	0	240	155	11/21/78	11/21/78
7	AS 332C	9921	411	343	3.3	15100	4500	1250	8300	5000	6000	2500	1600	218	550	150	10/14/81	10/14/81
8	BV 234 LR	28000	2090	730	5.4	6467	-	-	7400	4400	2700	500	1180	257	295	149	06/19/81	06/19/81

Takeoff Transmission Power Available (TR TO). The takeoff power available limit of the main gearbox in units of horsepower.

Maximum Continuous Transmission Power Available (TR MAX). The main gearbox maximum continuous power available limit, in horsepower.

Single Engine Transmission Power Available (TR 1ENG). The main gearbox power available limit for a twin engine aircraft in the one engine inoperative condition, in horsepower.

Number of Main Rotor Blades (RS BLM). The number of blades in the main rotor.

Number of Tail Rotor Blades (RS BLT). The number of tail rotor blades.

Main Rotor Revolutions Per Minute (RS RPMM). The number of revolutions per minute of the main rotor.

Tail Rotor Revolutions Per Minute (RS RPMT). The number of tail rotor revolutions per minute.

Main Rotor Diameter (RS DIAM). The diameter of the main rotor of the aircraft, in feet.

Tail Rotor Diameter (RS DIAT). The tail rotor diameter of the aircraft, in feet.

Main Rotor Chord (RS CHORM). The chord of the main rotor as measured in feet.

Tail Rotor Chord (RS CHORT). The tail rotor's chord, in feet.

Main Rotor Disc Area (RS DAREAM). The disc area of the main rotor in feet squared.

Tail Rotor Disc Area (RS DAREAT). The tail rotor disc area in terms of square feet.

Main Rotor Disc Loading (RS DISCLD). The disc loading in dimensions of pounds per square feet. Disc loading is calculated by dividing the helicopter's maximum gross weight by the main rotor disc area.

Main Rotor Power Loading (RS PWRLD). The power loading is determined by dividing the helicopter's maximum gross weight by the total takeoff power available and is measured in units of pounds per horsepower.

Fuselage Length (EX LFUSE). The length of the fuselage is measured in feet from nose to tail of the aircraft and may include portions of the vertical stabilizer.

Fuselage Length With Tail Rotor Turning (EX TTURN). The length of the fuselage is measured in feet and includes the extreme point described by the tail rotor arc.

Fuselage Length With Main and Tail Rotors Turning (EX BTURN). The length of the fuselage is measured in feet and includes the extreme points of the arcs described by both the main and tail rotors.

Fuselage Width (EX WFUSE). The maximum fuselage width of the aircraft measured in feet.

Widest Point Width (EX WIPT). The widest point of the aircraft in units of feet as determined by any fuselage structure which may include the horizontal stabilizer.

Landing Gear Type (EX GEPT). The type of landing gear (skid or wheel) and configuration if fitted with wheels (tri or quad with single (SF) or dual (DF) wheels in forward position and single wheels in aft position (SA)).

Landing Gear Width (EX WLGP). The width of the landing gear measured in feet.

Landing Gear Length (EX GELG). The length of the landing gear measured in feet.

Ground To Main Rotor Hub Height (EX HUBHT). The height measured in feet from the ground to the top of the main rotor hub of the aircraft.

Ground To Tail Rotor Arc Height (EX TARCHT). The height measured in feet from the ground to the top of the arc described by the tail rotor.

Ground Clearance (EX GFUSE). The height measured in feet from the ground to the lowest point on the aircraft.

Standard Seating (AC SEAT). The normal seating capacity of the aircraft in terms of number of persons.

High Density Seating (AC DENS). The absolute seating capacity of the aircraft in terms of the number of persons.

Maximum Gross Weight (WT GROSS). The maximum gross weight of the aircraft in pounds.

Empty Gross Weight (WT EMPTY). The empty gross weight of an aircraft in normal configuration with oil and undrainable fuel, in pounds.

Fuel Weight (WT FUEL). The weight of a standard tank of fuel, in pounds.

External Load Weight (WT LOAD). The maximum weight in pounds of any sling load or material that can be suspended from the helicopter's cargo hook.

Standard Fuel Tank Capacity (FUE TANK). The standard fuel capacity of the aircraft, in gallons.

Maximum Range (RAN MAX). The maximum distance in nautical miles that the aircraft can achieve at maximum gross weight with a full fuel load at sea level on a standard day.

Endurance (RAN ENDCR). The maximum time the helicopter can stay aloft at economy cruise speed in hours.

Service Ceiling (PER SC). The maximum operating altitude of the aircraft in feet at sea level and standard day temperature.

Single Engine Service Ceiling, Standard Day (PER SC1STD). The maximum operating altitude in feet of a twin engine aircraft with one engine inoperative at sea level on a standard day temperature.

Single Engine Service Ceiling, Hot Day (PER SC1HOT). The maximum operating altitude in feet of a twin engine aircraft with one engine inoperative at sea level and hot day temperature.

Hover Ceiling, In-Ground-Effect, Standard Day (PER HIGE). The maximum altitude in feet at which an aircraft can hover in-ground-effect on a standard day.

Hover Ceiling, In-Ground-Effect, Hot Day (PER HIGEHT). The maximum altitude in feet at which an aircraft can hover in-ground-effect on a hot day.

Hover Ceiling, Out-of-Ground-Effect, Standard Day (PER HOGE). The maximum altitude in feet at which an aircraft can hover out-of-ground effect on a standard day.

Hover Ceiling, Out-of-Ground-Effect, Hot Day (PER HOGEHT). The maximum altitude in feet at which an aircraft can hover out-of-ground effect on a hot day.

Oblique Rate of Climb (PER ROCOB). The maximum rate of climb in feet per minute of an aircraft with some forward airspeed.

Vertical Rate of Climb (PER ROCVE). The rate of climb in feet per minute of an aircraft with no forward airspeed.

Single Engine Rate of Climb (PER ROC1). The maximum rate of climb in feet per minute of a twin engine aircraft with one engine inoperative.

Never Exceed Speed (PER VNE). The maximum allowable speed of the aircraft measured in knots.

VFR Certification Date (CERT VFR). The date of FAA certification for visual flight.

IFR Certification Date (CERT IFR). The date of the FAA certification for instrument flight.

A number of data sources were used to generate the physical and performance data of this report. Helicopter flight manuals were obtained from helicopter manufacturers and in some cases, flight test results were consulted. The Helicopter Blue Book, published by Helicopter Financial Services Inc., was also referenced.

Helicopter flight manuals are the most reliable data source. Generally, a flight manual contains descriptions of the aircraft dimensions, physical characteristics, operating limitations, normal and emergency procedures, performance data, weight and balance data, systems and servicing information, conversion charts and tables, optional equipment, and FAA approved supplements. However, not all flight manuals contain the same detail of description. Table 2 compares the information needed to generate the departure performance data contained in this report with its availability in each of the eight flight manuals and other data sources used for this study. An "F" marked in a column indicates that the data was available in the flight manual. Information needed that was not available in the flight manual was requested from the FAA coordinator at each manufacturer's facility. The information supplied by this resource is indicated by an "M". Subcontractor-generated data is represented by an "S". As a last resort, data was gathered from the Helicopter Blue Book and is indicated by a "B". The performance data obtained from the Blue Book was considered to be the least reliable in that the specific conditions stated at which the data were valid often were not in agreement with data contained in the flight manual for those same conditions.

Table 3 is a traceability matrix that directly relates the physical database file components to their source for each of the eight aircraft. The symbols used are the same as those in table 2 except for the addition of two new symbols; an "N" indicates the data type is not applicable to the specific aircraft, and a "-" shows that the data could not be obtained.

PERFORMANCE DATA GENERATION

This section elaborates on the intermediate steps taken to prepare for the generation of approach and departure profiles. After the data sources were collected, information to develop departure profiles for different combinations of gross weight, altitude and temperature were not readily available. To obtain this information SCT employed a subcontractor which used the Helicopter Sizing and Performance Computer Program (HESCOMP) to generate rates of climb, accelerations, distances and times to accelerate and maximum climb angles as a function of forward airspeed for the desired combinations of gross weight, altitude and temperature for each aircraft. This computer model was originally developed by Boeing Vertol Company under contract to NASA and the U.S. Navy. HESCOMP is widely accepted by industry and used to define design requirements to meet specified mission requirements and to perform sensitivity studies involving both design and performance trade-offs.

The application of HESCOMP pertaining to this study was in the simulation of helicopter mission performance for which sizing details were known. HESCOMP was modified to include a more accurate representation of low speed power characteristics, more detailed weights algorithms, center of gravity locations, advanced rotor characteristics and maneuver analyses. When available, dimensional, propulsion, aerodynamics, weights, rotor limits, atmospheric, mission profile, rotor tip speed schedule and engine cycle information, and rotor and propulsion performance data were input into HESCOMP. A 10 percent data accuracy was achieved using the model. The aircraft data used in the HESCOMP calculations and the resultant performance data was then sent to aerodynamacists at each of the manufacturers. Upon review, three aircraft were cited as having flawed data; the S76A, the BV234 LR and the AS355F. The performances of these aircraft were then recomputed by a

TABLE 2. PERFORMANCE DATA SOURCE TRACEABILITY MATRIX

HELICOPTER	GROSS WEIGHT	MAXIMUM POWER AVAILABLE	ENGINE TORQUE LIMIT	MINIMUM POWER REQUIRED	TRUE AIRSPEED AT MINIMUM POWER REQUIRED	POWER REQUIRED TO HOVER	FORWARD RATE OF CLIMB AT AN AIRSPEED	HORIZONTAL AIRSPEED CORRESPONDING TO FORWARD RATE OF CLIMB
F 28F	F	F	F	M	M	M	F	F
MD 500E	F	F	F	M	M	M	M	M
B 206B III	F	B	F	M	M	M	F	F
AS 355F	F	B	F	M	M	M	F	F
BO 105 CBS	F	B	F	S	F	S	F	F
S 76A	F	F	F	M	M	M	F	F
AS 332C	F	F	F	M	M	M	F	F
BV 234 LR	F	M	F	M	M	M	M	M

F - FLIGHT MANUAL   M - MANUFACTURER   B - BLUE BOOK   S - SUBCONTRACTOR DATA

TABLE 3. PHYSICAL DATA BASE TRACEABILITY MATRIX

HELICOPTER	ENGINE MANUFACTURER	NO. OF ENGINES	ENGINE MODEL	TAKEOFF POWER	MAX. CONTINUOUS POWER	SINGLE ENGINE 30 MINUTE POWER	TAKEOFF TRANSMISSION POWER	MAXIMUM CONTINUOUS TRANSMISSION POWER	SINGLE ENGINE TRANSMISSION POWER	NO. OF MAIN ROTOR BLADES	NO. OF TAIL ROTOR BLADES	MAIN ROTOR RPM	TAIL ROTOR RPM	MAIN ROTOR DIAMETER	TAIL ROTOR DIAMETER	MAIN ROTOR CHORD	TAIL ROTOR CHORD	MAIN ROTOR DISC AREA	TAIL ROTOR DISC AREA	MAIN ROTOR DISC LOADING	MAIN ROTOR POWER LOADING	FUSELAGE LENGTH	FUSELAGE LENGTH WITH TAIL ROTOR TURNING	FUSELAGE LENGTH WITH BOTH ROTORS TURNING	FUSELAGE WIDTH	WIDEST POINT WIDTH	LANDING GEAR TYPE
F 28F	F	F	F	F	F	N	M	M	N	F	F	F	M	F	F	F	F	F	F	B	B	B	F	B	M	F	F
MD 500E	F	F	F	F	M	N	M	M	N	F	M	F	M	F	M	F	F	F	M	M	M	M	M	F	F	F	F
B 206B III	F	F	F	B	B	N	B	B	N	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
AS 355F	F	F	F	B	B	--	B	--	--	F	F	F	B	F	F	B	B	B	B	B	B	F	F	F	F	F	F
BO 105 CBS	F	F	F	B	B	--	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
S 76A	F	F	F	F	M	M	B	B	B	F	F	B	M	F	F	B	B	B	B	B	B	F	B	F	F	F	F
AS 332C	F	F	F	F	F	F	F	--	F	F	F	F	F	F	F	B	B	B	B	B	B	B	F	F	F	F	F
BV 234 LR	F	F	F	B	F	F	B	B	B	F	F	M	M	M	M	M	M	M	M	M	M	F	N	F	F	F	F

F = FLIGHT MANUAL   M = MANUFACTURER   B = BLUE BOOK   -- = NOT AVAILABLE   N = NOT APPLICABLE   S = SUBCONTRACTOR DATA

TABLE 3. PHYSICAL DATA BASE TRACEABILITY MATRIX (continued)

HELICOPTER	LANDING GEAR WIDTH	LANDING GEAR LENGTH	GROUND TO MAIN ROTOR HUB HEIGHT	GROUND TO TAIL ROTOR ARC HEIGHT	GROUND CLEARANCE	STANDARD SEATING	HIGH DENSITY SEATING	MAXIMUM GROSS WEIGHT	EMPTY GROSS WEIGHT	FUEL WEIGHT	EXTERNAL LOAD WEIGHT	STANDARD FUEL TANK CAPACITY	MAXIMUM RANGE	ENDURANCE	SERVICE CEILING	SINGLE ENGINE SERVICE CEILING, STANDARD DAY	SINGLE ENGINE SERVICE CEILING, HOT DAY	HOVER CEILING, IGE, STANDARD DAY	HOVER CEILING, IGE, HOT DAY	HOVER CEILING, OGE, STANDARD DAY	HOVER CEILING, OGE, HOT DAY	OBLIQUE RATE OF CLIMB	VERTICAL RATE OF CLIMB	SINGLE ENGINE RATE OF CLIMB	NEVER EXCEED SPEED	VFR CERTIFICATION DATE	IFR CERTIFICATION DATE
F 28F	F	F	F	F	M	B	B	F	F	B	B	F	B	F	F	N	N	F	F	F	F	M	S	N	F	F	N
MD 500E	F	M	F	M	F	M	M	F	M	M	B	M	M	M	B	N	N	F	F	F	F	F	M	N	F	F	N
B 206B III	B	M	B	M	B	B	B	F	B	B	B	B	B	B	B	N	N	F	F	F	F	F	M	N	F	F	N
AS 355F	F	--	F	B	F	B	B	F	B	B	B	F	B	B	B	B	--	F	F	F	F	F	S	F	F	B	B
BO 105 CBS	B	--	B	B	B	B	B	F	B	B	B	B	F	F	B	F	F	F	F	F	F	F	F	F	B	B	B
S 76A	F	F	M	F	B	M	M	F	M	M	B	M	M	B	M	M	M	F	F	F	F	F	S	F	M	F	F
AS 332C	F	F	F	F	B	F	B	F	B	B	B	F	B	F	F	F	F	F	F	F	F	F	S	F	F	F	F
BV 234 LR	B	F	F	N	--	M	M	F	B	B	B	F	M	M	M	F	F	F	F	M	M	F	M	F	F	F	F

F = FLIGHT MANUAL   M = MANUFACTURER   B = BLUE BOOK   -- = NOT AVAILABLE   N = NOT APPLICABLE   S = SUBCONTRACTOR DATA second subcontractor. Summary reports of the analysis completed by each of the subcontractors are contained in this report as appendix A. Assumptions, data traceability and a discussion of data accuracy are covered.

The preparations made for the generation of approach profiles included the analysis of previously published approach test data. A NASA study (NASA-TN-D-8275) presented the variation in approach profile shape as a function of approach speed determined from a total of 236 visual approaches flown by 4 helicopters (table 4). The results of the study showed approach profile shape to be independent of helicopter gross weight. Average altitude profiles from initial conditions of 500 feet at 50, 80 and 100 knots are shown in figure 2. The altitude standard deviations are not significantly affected by variations in initial airspeed.

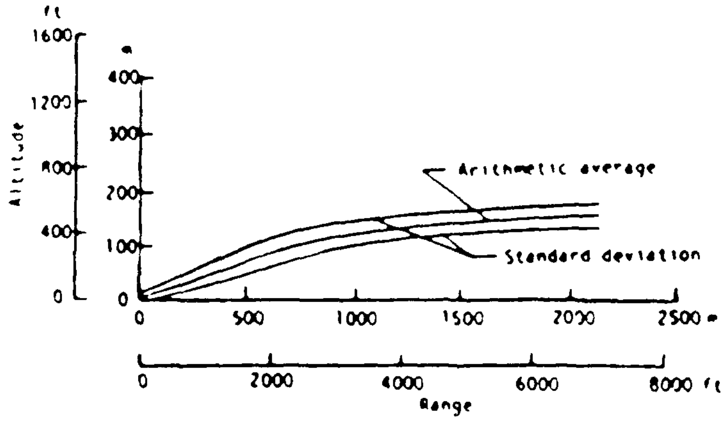
An example of the characteristic approach profile shape is shown in figure 3. This shape is representative of all data from the NASA study, but is graphed from specific data generated by one pilot performing two approaches at each airspeed. This characteristic shape results from pilots flying approaches they perceive as natural from a pilot's perspective and comfortable to commercial passengers. As the initial airspeed decreases the concave down portion of the approach is accentuated and the interception of the desired slope is delayed. Slope lines of 8:1, 7:1, 6:1 and 5:1 have been sketched into the figure and show that the characteristic approaches (except for a segment between 500 and 2500 feet from the helipad of the 100 knot approach) do not break the current 8:1 approach surface.

Test data from FAA Technical Center VMC approach testing were also analyzed. The tests were performed to validate current FAA heliport design approach surfaces criteria and to recommend modifications to the surfaces, if appropriate. Heliport visual approach test data are presented in DOT/FAA/CT-TN87/40. A total of 270 straight-in approaches were performed, 108 for which no specific approach angles were required to be flown by the pilot. The remaining 162 approaches were comprised of 54 approaches flown per required approach angle (7, 8 and 10 degrees). Ninety approaches were performed using a Sikorsky S-76, 130 using a Bell UH-1H and 50 using a Hughes OH-6. Initial approach conditions consisted of a 70 knot entrance into the approach from an altitude of 500 feet.

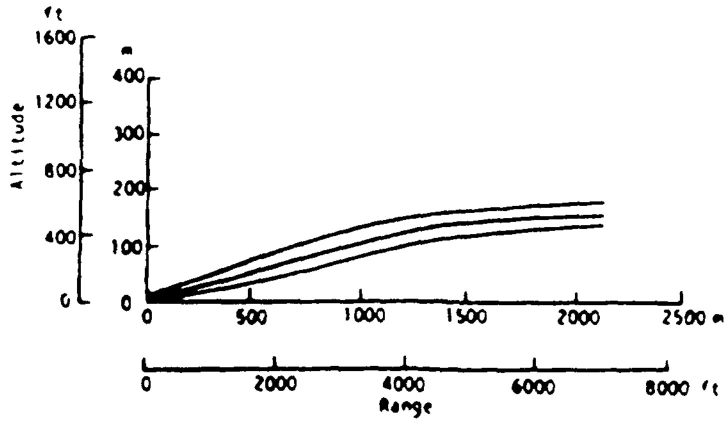
Initially the approach test data were assumed to be characterized by a Gaussian (Normal) distribution. Questions arose during the data analysis regarding the validity of this assumption. A follow-up project was established to study the characteristics of the underlying distributions of the approach test data. The results of this effort are reported in "Analysis of Distributions of Visual Meteorological Conditions (VMC) Heliport Data," DOT/FAA/CT-TN89/67. The report is written in two volumes. Volume 1 is a summary report and volume 2 contains 1,054 pages including graphs depicting the results of the graphical method used to determine the approach data distribution. The results of the effort showed that the assumption of a Normal distribution was not valid. The majority of the data seemed to exhibit characteristics of some form of the Beta distribution. Airspace

TABLE 4. NASA APPROACH TEST HELICOPTER CHARACTERISTICS

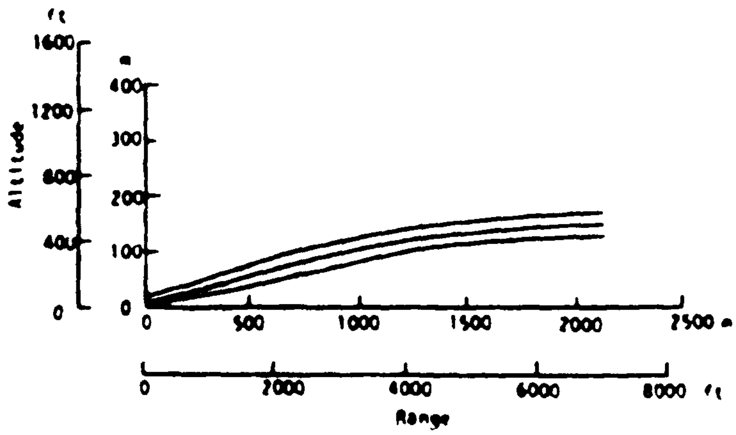
Characteristic	Helicopter 1	Helicopter 2	Helicopter 3	Helicopter 4
Type	Light observation	Light utility	Medium transport	Medium transport
Maximum gross weight	12 233 N (2750 lb)	37 810 N (8500 lb)	68 947 N (15 500 lb)	84 961 N (19 100 lb)
Maximum airspeed	115 knots	120 knots	120 knots	142 knots
Configuration	Single rotor	Single rotor	Tandem rotor	Single rotor
Disk loading	148.4 Pa (3.1 lb/ft^2)	225.0 Pa (4.7 lb/ft^2)	201.1 Pa (4.2 lb/ft^2)	301.6 Pa (6.3 lb/ft^2)
Power plant	Single turbine	Single turbine	Twin turbine	Twin turbine
Total power	410 kW (550 hp)	820 kW (1100 hp)	1565 kW (2100 hp)	1565 kW (2100 hp)
Control stabilization	None	Augmented rate (gyro bar)	Rate	Attitude



50 knots, 150 m (500 ft).



80 knots, 150 m (500 ft).



100 knots, 150 m (500 ft).

FIGURE 2. NASA VFR ALTITUDE PROFILES

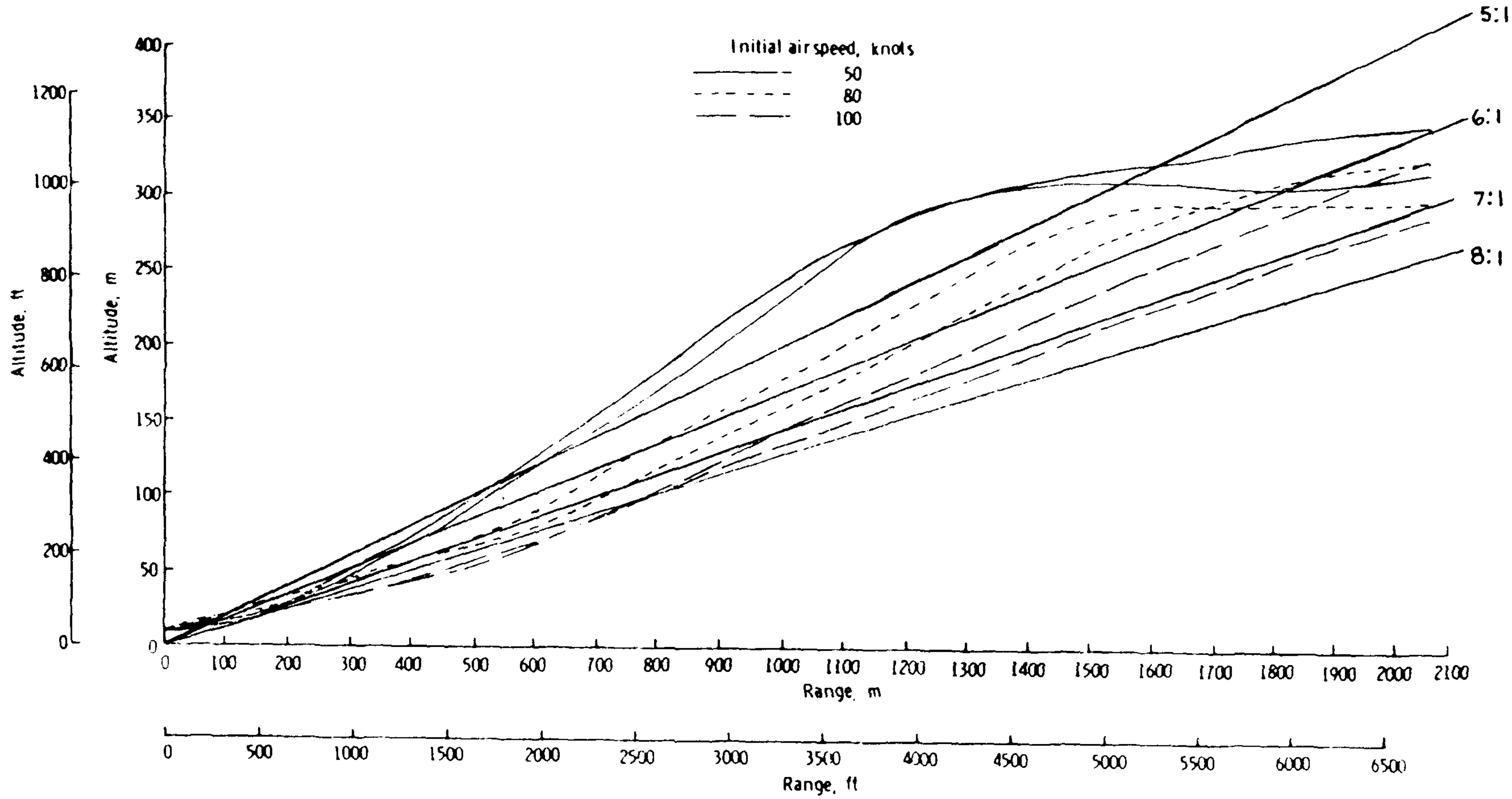


FIGURE 3. NASA CHARACTERISTIC APPROACH PROFILES

envelopes depicting 10^{-7} target levels of safety (6 sigma) were computed for the Normal, Beta, and Gamma distributions and plotted on graphs along with the mean approach data.

Figures 4 through 6 are graphs depicting FAATC S-76 approach test data excerpted from volume 2 of "Analysis of Distributions of Visual Meteorological Conditions (VMC) Heliport Data." These figures show the mean approach profiles and the 10^{-7} target level of safety envelopes for each of these approach angles flown (7, 8, and 10 degrees). It is apparent that the relative deviation increases as the approach angle increases. These figures also show that the 10^{-7} envelope of the Beta distribution usually falls well inside the envelope of the Normal distribution. This shows the overly conservative nature of the Normal distribution when applied to the VFR approach data. At all three angles the mean profiles show the characteristic flight path to be on or above the required slope within 2000 feet of the helipad. A composite approach profile plot for the three angles flown is shown as figure 7. This figure was taken from volume 2 of "Heliport Visual Approach and Departure Airspace Tests." Test pilots rated all three angles as adequate with respect to safety, but considered both pilot visibility and passenger comfort as issues for the 10 degree approach.

Table 5 illustrates the approach rates of descent that must be maintained to descend along a specified slope at a constant airspeed. Minimum autorotation rates of descent for each helicopter in this study were determined for each combination of gross weight, altitude and temperature. The smallest of these values per helicopter was chosen to be the minimum autorotation rate of descent for all conditions. Four hundred feet per minute was subtracted from each value to yield a value for the maximum assumed approach rate of descent attainable without entering into autorotation. These are shown in table 6 and corresponds to minimum power required airspeeds. Four hundred feet per minute was used to provide an acceptable margin between the autorotation and approach rates of descent to provide a control margin which allows for 1) variations in specific helicopter performance, 2) light tailwind, and 3) airspeed variations.

A comparison of tables 5 and 6 determine the combinations of approach slopes and speeds each helicopter can safely achieve with respect to the assumptions previously made, without entering into autorotation. When the approach rate of descent is greater than the helicopter's maximum assumed rate of descent, the approach is undesirable. The achievable approach slopes resulting from these comparisons are shown in table 7. The shaded blocks of the table indicate the approach speeds at their corresponding slopes are undesirable. Based on the assumptions made, none of the aircraft listed can effect a 90 knot approach at the 5:1 slope, while half cannot effect the 70 knot approach at the same slope.

APPROACH PROFILES

Approach profiles were developed by considering the characteristic shape (figure 3) and its variations with initial approach speeds as determined by NASA (reference 16). FAATC test data from references 22 and 23 (figures 4 through 7) indicate that pilots can fly on or above slope approaches (7, 8, 10 degrees) though pilot workload tends to

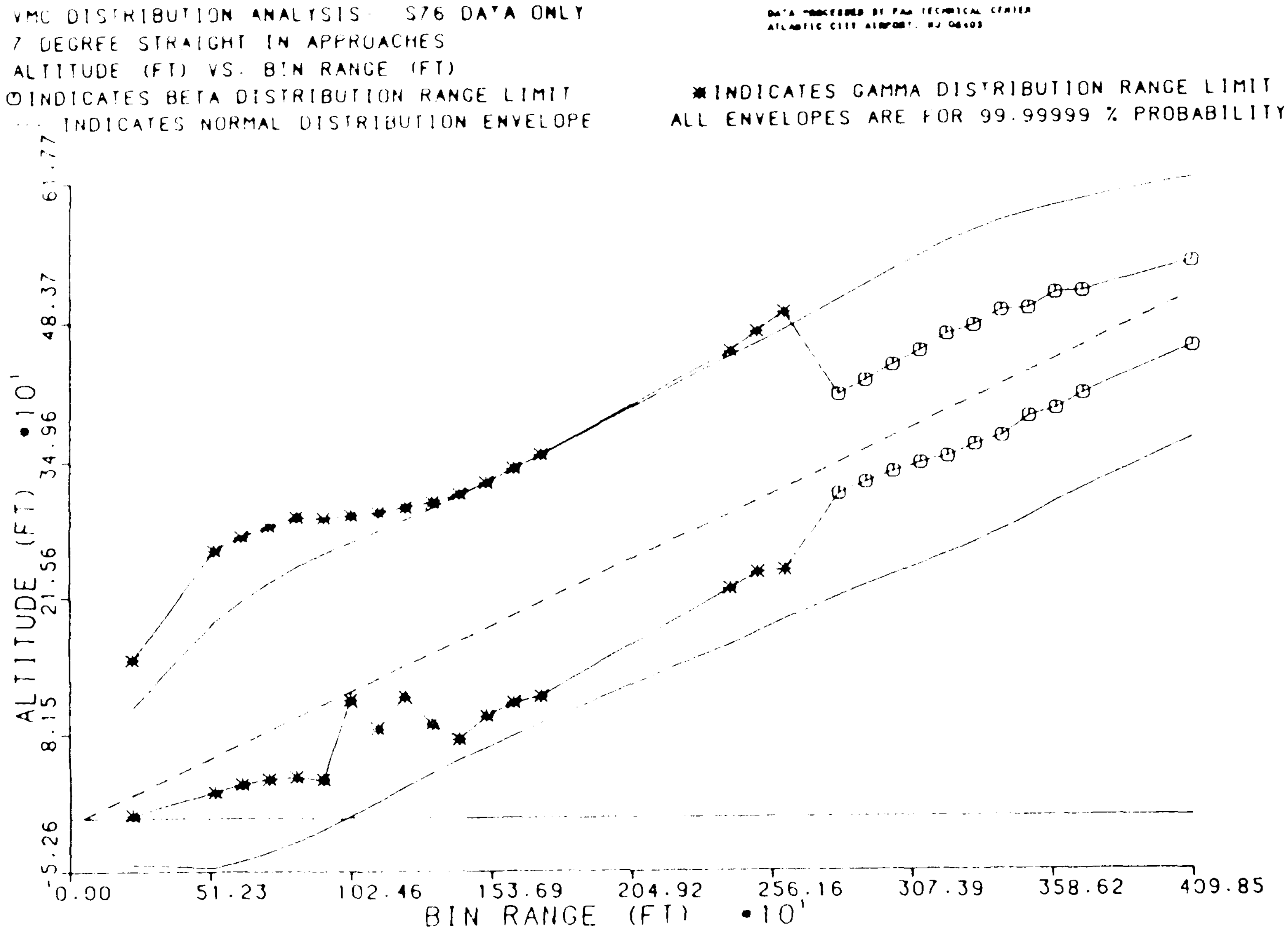


FIGURE 4. FAATC S 76 7.125 DEGREE APPROACH PROFILE

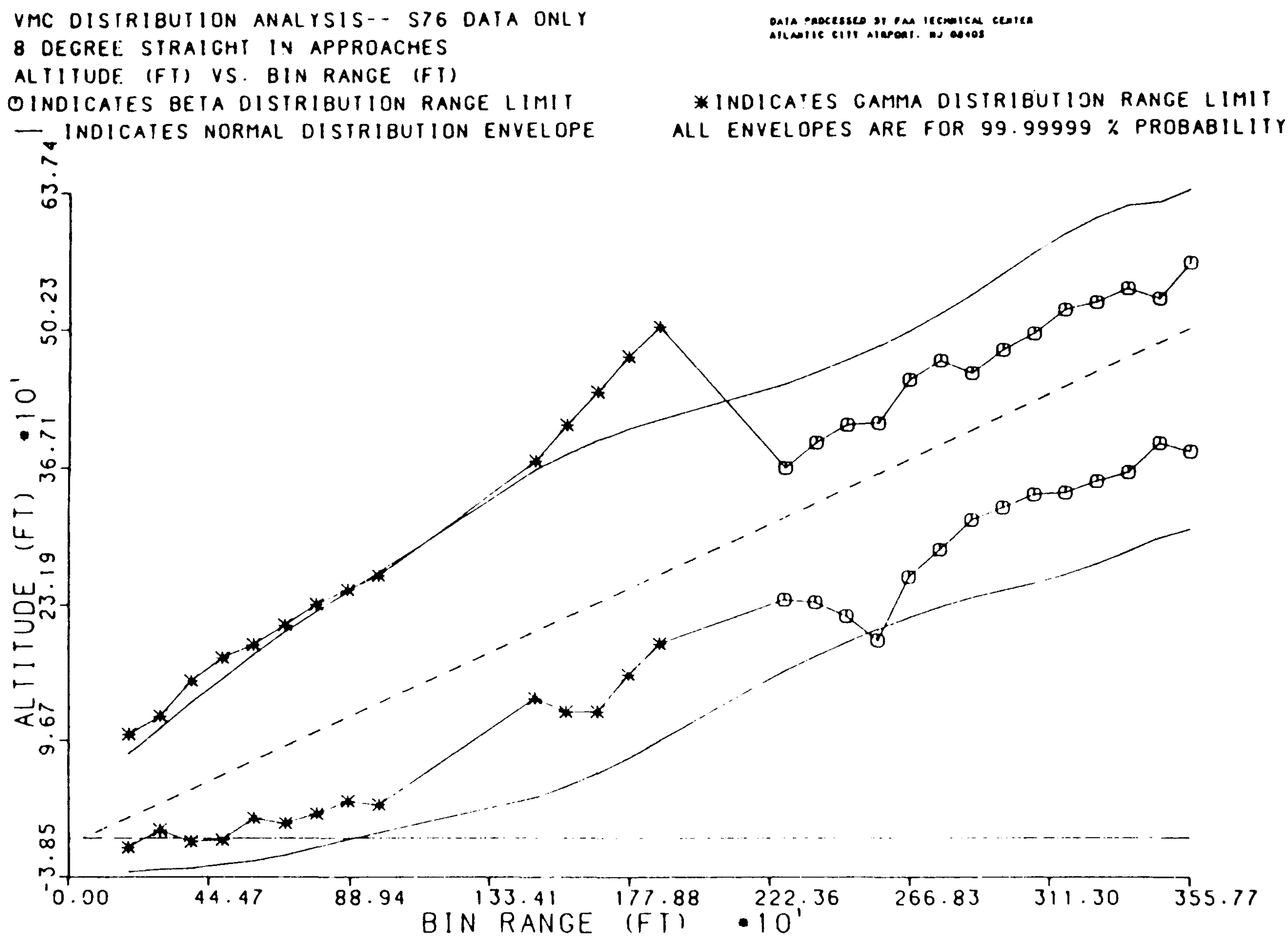


FIGURE 5. FAATC S 76 8.0 DEGREE APPROACH PROFILE

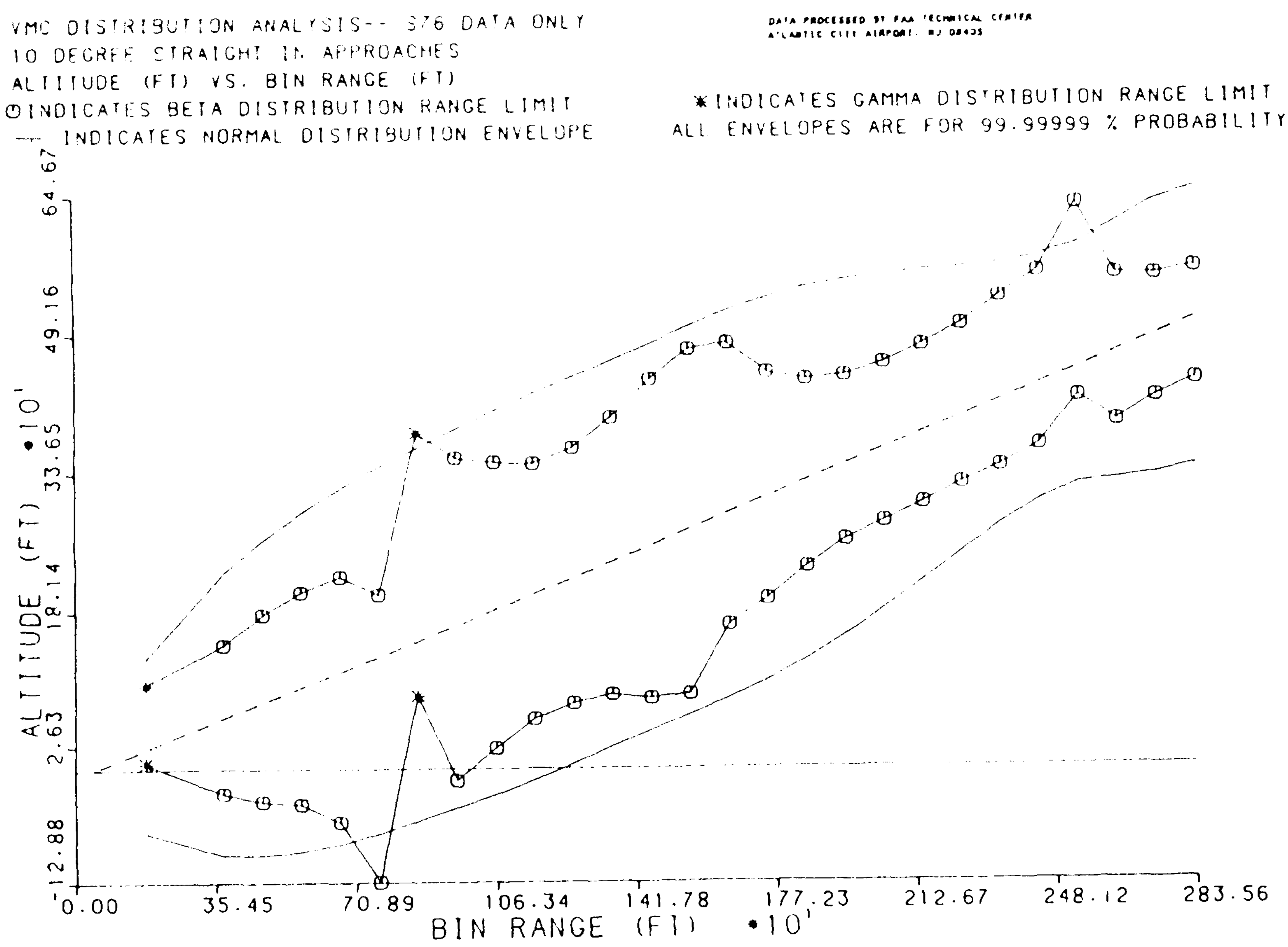


FIGURE 6. FAATC S 76 10.0 DEGREE APPROACH PROFILE

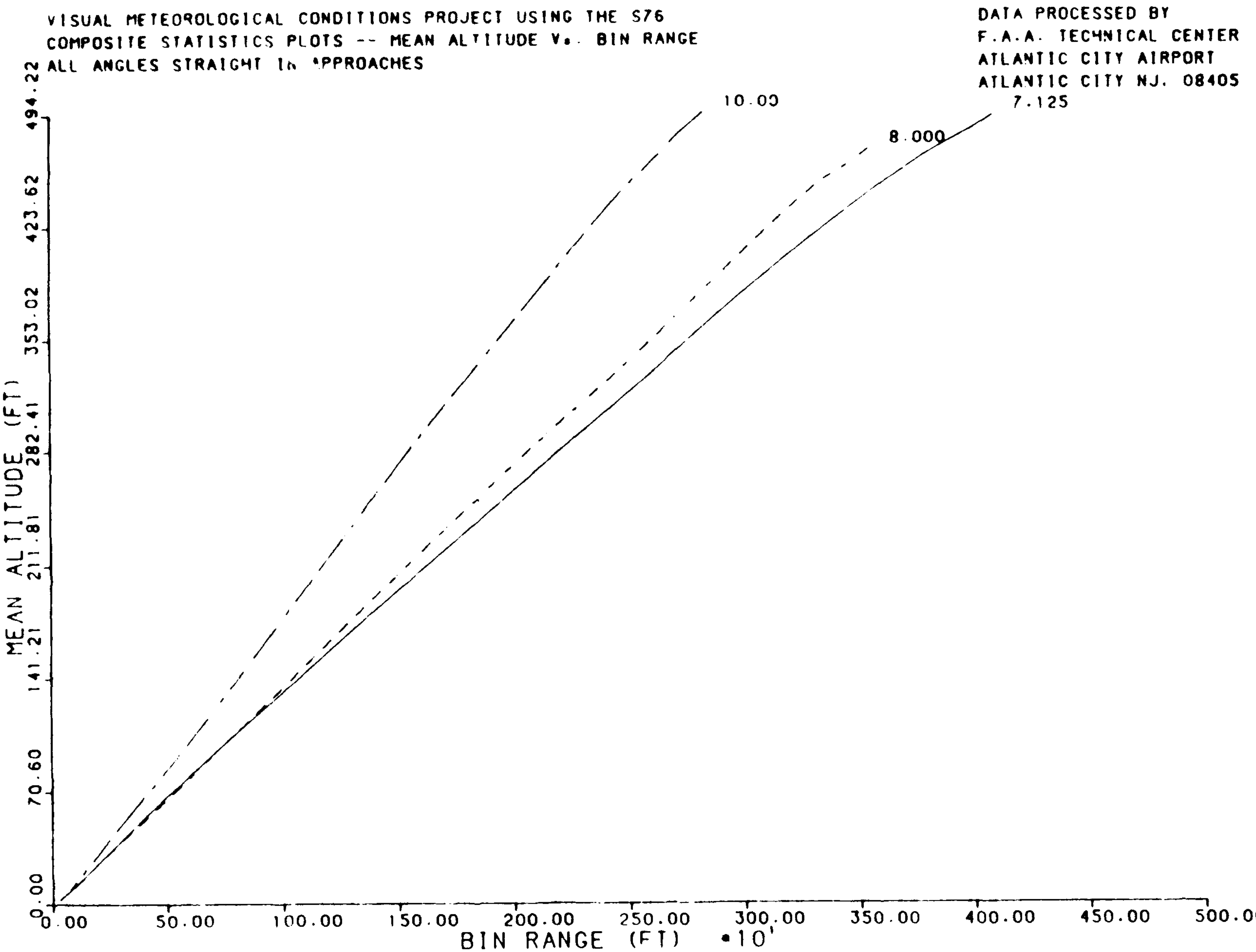


FIGURE 7. FAATC S 76 COMPOSITE APPROACH PROFILES

TABLE 5. APPROACH RATE OF DESCENT LIMITS

APPROACH SLOPE	APPROACH RATE OF DESCENT LIMITS (FT/MIN)			
	APPROACH SPEED (KNOTS)			
	90	70	50	40
8 : 1	1131	879	628	502
7 : 1	1285	999	714	571
6 : 1	1504	1170	836	668
5 : 1	1823	1418	1013	810

TABLE 6. MAXIMUM RATES OF DESCENT

HELICOPTER MODEL	MAXIMUM RATE OF DESCENT (FT/MIN)
F 28F	890
MD 500E	1400
B 206B III	1110
AS 355F	1540
BO 105 CBS	1510
S 76A	1250
AS 332C	1670
BV 234 LR	1540

TABLE 7. ACHIEVABLE APPROACH SLOPES

HELICOPTER MODEL	ACHIEVABLE APPROACH SLOPES							
	APPROACH SPEED (KNOTS)							
	8 : 1		7 : 1		6 : 1		5 : 1	
F 28F	N/A	70	N/A	70	N/A	70	N/A	70
	50	40	50	40	50	40	50	40
MD 500E	90	70	90	70	90	70	90	70
	50	40	50	40	50	40	50	40
B 206B III	90	70	90	70	90	70	90	70
	50	40	50	40	50	40	50	40
AS 355F	90	70	90	70	90	70	90	70
	50	40	50	40	50	40	50	40
BO 105 CBS	90	70	90	70	90	70	90	70
	50	40	50	40	50	40	50	40
S 76A	90	70	90	70	90	70	90	70
	50	40	50	40	50	40	50	40
AS 332C	90	70	90	70	90	70	90	70
	50	40	50	40	50	40	50	40
BV 234 LR	90	70	90	70	90	70	90	70
	50	40	50	40	50	40	50	40

LEGEND

	Operationally Desirable Approach Speeds/Slopes
	Operationally Undesirable Approach Speeds/Slopes
N/A	**Not Applicable (90 kt Speed Exceeds Aircraft V_{ne})**

increase and comfort levels tend to decrease. Figures 8 through 11 show characteristic approaches made at initial speeds of 40, 50, 70 and 90 knots for various slopes. As the initial speed increases, the slope is intercepted sooner. The approaches are flown to a 10 foot hover over a 100 foot diameter pad.

Manufacturers' recommended flight manual approach procedures for each helicopter used in this study are shown in table 8. Table 7 coupled with these procedures (when they provide adequate information) can be used to determine desirable approach profiles for each aircraft. For example, the F 28F flight manual approach procedure recommends an approach speed of 52 knots at 8 to 10 degrees. Table 7 indicates that the F 28F, based on the assumptions made, cannot fly 70 knot approaches at 8, 9.5 or 11.3 degrees and 50 knot approaches at 11.3 degrees. Additionally, 90 knot approaches for all slopes shown are unusable as the approach speed exceeds the designated V_{ne} for the aircraft at gross weights greater than 2,350 lbs. Therefore, the 70 knot 8:1 approach, the 50 knot 8:1, 7:1 and 6:1 approaches' and 90 knot approaches of figure 9 are desirable approaches for the F 28F. Coupled with the approach procedure in table 8, realistic approaches for the F 28F are the 50 knot 7:1 and 6:1 approaches.

DEPARTURE PROFILES

Departure profiles were generated by integrating the subcontractor-provided data with departure procedures listed in flight manuals. A computer model was developed for each helicopter takeoff procedure and tailored to the individual helicopter's characteristics. Gross weight limits, hover performance and temperature, height-velocity and altitude limitations were incorporated in the models. The takeoff procedures recommended in each flight manual are listed in table 9.

In developing each departure profile the horizontal distances required to intercept 8:1, 7:1, 6:1 and 5:1 slopes during departure were calculated. In addition to using the takeoff procedures stated in the flight manuals, "optimum" departure procedures were derived. These departure procedures were based on obeying the limits of the H-V diagram by flying a five knot parallel path to the diagram. An example of this is shown in figure 12 and is labeled "H-V+5 KTS". When the flight manual departure procedure was not defined well enough, one was developed to consist of a level acceleration, slight rotation and climb out at the best rate of climb speed.

Category A departures were provided for three aircraft. For the BV 234LR, only one departure procedure was recommended. This departure procedure was modified to create an additional procedure by climbing out at VToss instead of best rate of climb speed.

The departure profiles are contained in appendix B of this report.

DISCUSSION

The FAATC test data has shown that the airspace required for approaches is more a function of approach slope and pilot skill than aircraft performance. As figures 8 through 11 indicate, a pilot can fly an approach above or on the desired slope, if required. At greater

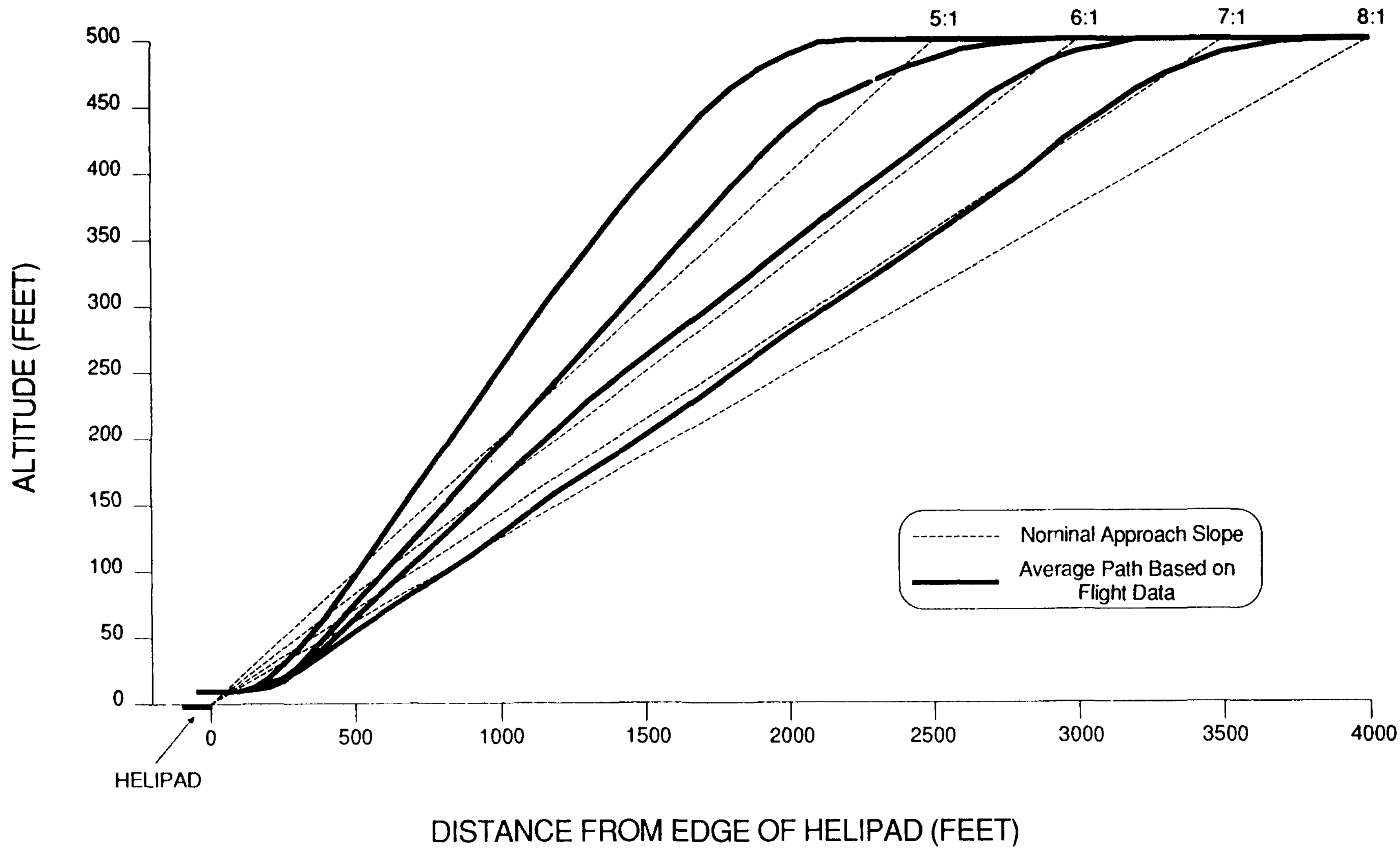


FIGURE 8. 40 KNOTS APPROACH PROFILES

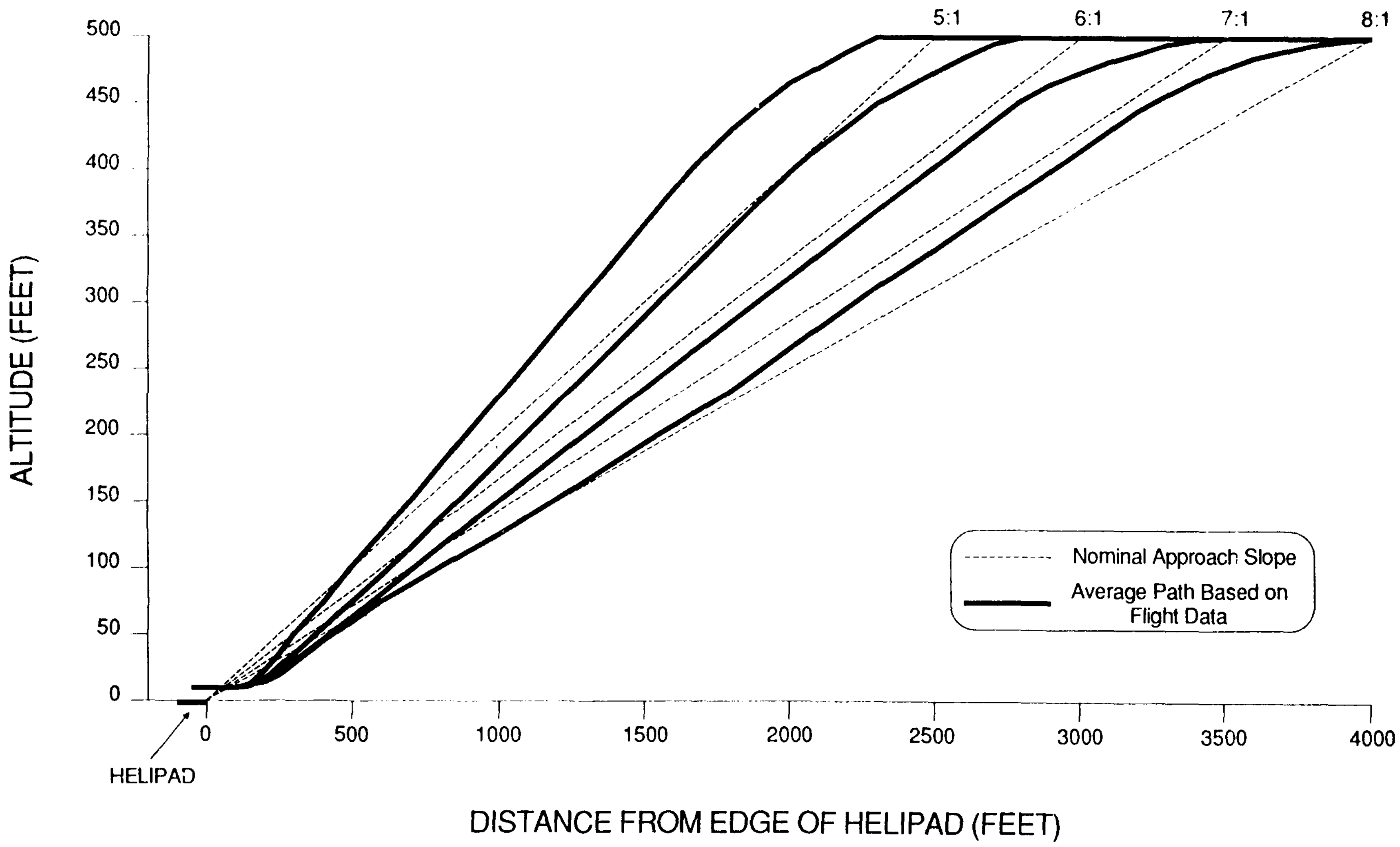


FIGURE 9. 50 KNOTS APPROACH PROFILES

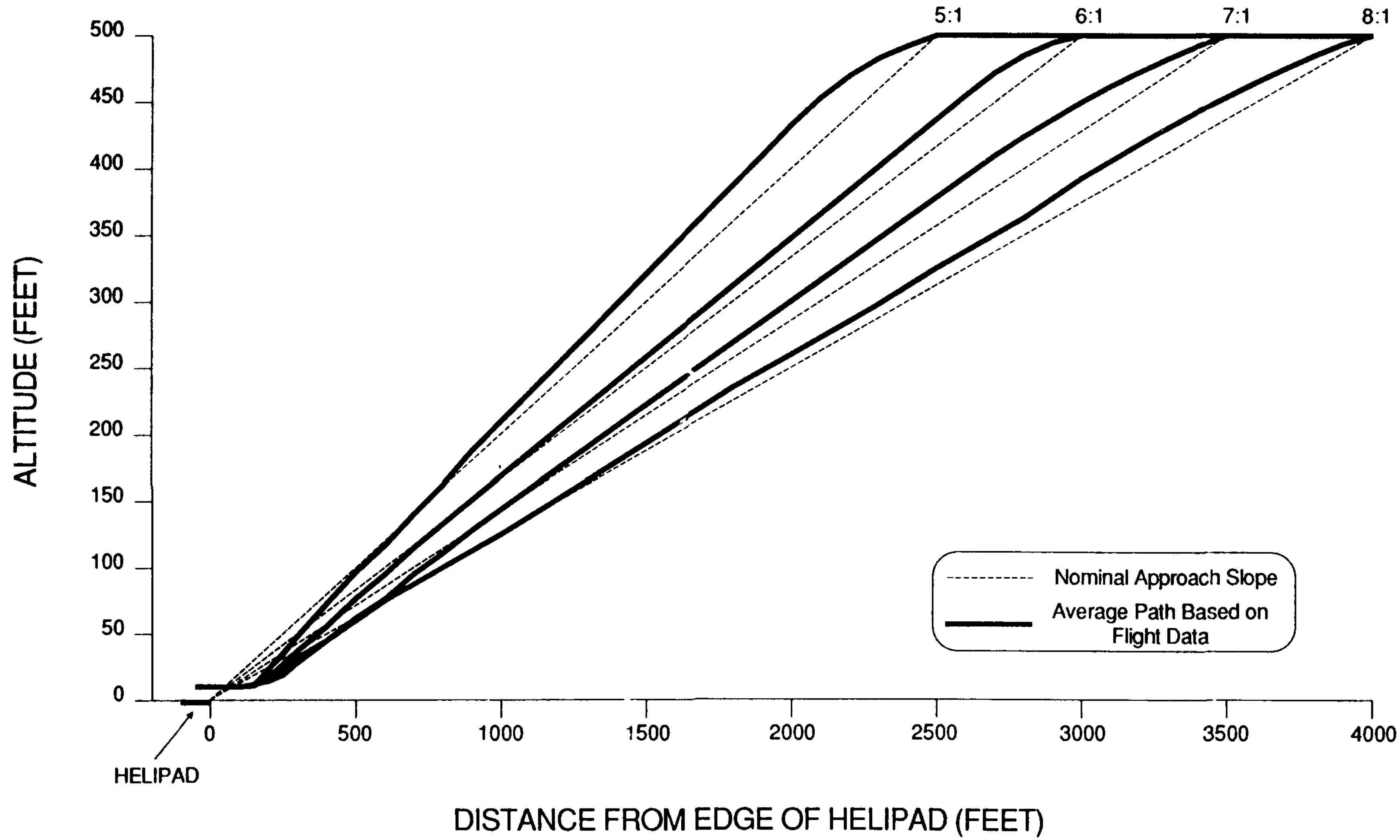


FIGURE 10. 70 KNOTS APPROACH PROFILES

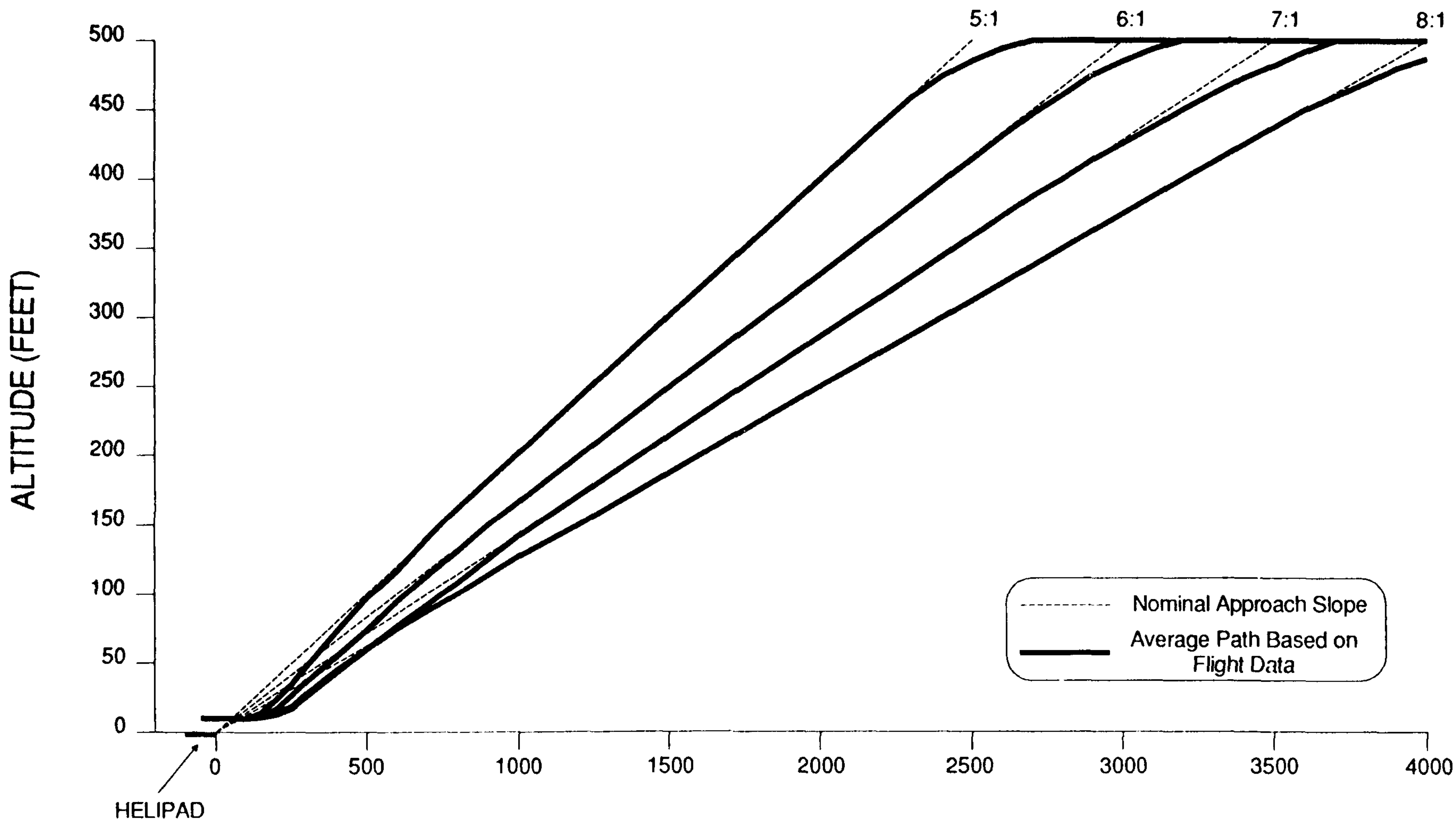


FIGURE 11. 90 KNOTS APPROACH PROFILES

TABLE 8. APPROACH PROCEDURES

HELICOPTER	FLIGHT MANUAL PROCEDURE
F 28F	Establish 8-10 degree approach angle and adjust airspeed to 52 knots. As landing area is approached, reduce airspeed and rate of descent until a zero ground speed hovering altitude of 2-5 feet is attained.
MD 500E	None.
B 206B III	Establish flight path as required for type of approach being made.
AS 355F	On final approach fly at about 45 knots. From hover, reduce pitch slowly and control landing until touchdown.
MBB BO 105 CBS	After entering approach pattern, reduce airspeed to 100-110 knots. Start final descent as directed and maintain airspeed to visual contact at decision height. Reduce airspeed and initiate a smooth flare.
S 76A	Cat A: Establish approach to arrive at landing decision point (100 ft above touchdown elevation at 50 knots and not more than 750 fpm rate of descent). Continue descent to about 50 feet above touchdown, then reduce the rate of descent with a cyclic flare to about 20 degrees nose up. Level the nose to 5-10 degrees at about 30 feet above touchdown. Establish hover. Cat B: Establish approach to arrive at a point 100 ft above the touchdown elevation at 50 knots at a rate of descent of no more than 500 fpm. Decelerate to pass 50 feet and 40 knots and continue approach and deceleration to hover.
AS 332C	Cat A: Proceed with final approach to reach landing decision point (100 ft at 40 knots with a rate of descent between 300-500 fpm). At the critical decision point slowly decrease speed to 30 knots and continue descent to height of 15 feet. Cat B: Gradually reduce speed to descend to 80 feet over the landing area at 40 knots. Recommended rate of descent is 300 fpm. From 15 ft gradually increase collective pitch to obtain final reduction in speed and to cancel rate of descent. Land.
BV 234 LR	Cat A: Stabilized descent at 400 fpm at 60 knots through landing decision point at 150 ft. Rotate helicopter nose up as required to arrive at the desired touchdown point.

TABLE 9. TAKEOFF PROCEDURES

HELICOPTER	FLIGHT MANUAL PROCEDURE
F 28F	Establish 2 ft HIGE, accelerate into effective translational lift, establish rate of climb and follow flight profile given in H-V diagram.
MD 500E	Follow recommended takeoff profile shown on H-V diagram.
B 206B III	Establish HIGE, accelerate to obtain desired rate of climb and airspeed.
AS 355F	Establish HIGE, initiate forward flight in a slight climb to 55 kt (optimum climb speed).
MBB BO 105 CBS	Establish 6 ft HIGE, level acceleration to 40 kt, climbing acceleration to CDP of 45 kt and 30 ft, climb out at best rate of climb.
S 76A	Cat A: Establish 5 ft HIGE, accelerate forward and maintain a 5-10 ft wheel height, at 35 kt rotate nose up and maintain 35 kt, at CDP of 40 ft accelerate to best rate of climb speed. Cat B: Establish 5 ft HIGE, accelerate forward and maintain a 5-10 ft wheel height, achieve 45-50 kt and raise nose to maintain 52 kt, climb until obstructions are cleared.
AS 332C	Cat A: Establish 15 ft HIGE, forward flight to best rate of climb speed, climb to constant best rate of climb speed. Takeoff-Transition to Forward Flight-Climb: Establish 15 ft HIGE, maintain acceleration path nearly parallel to the ground, at best rate of climb speed less 10 kt adjust to obtain and stabilize best rate of climb speed.
BV 234 LR	Cat A: Establish 15 ft HIGE, accelerate forward to 30 kt maintaining 10-20 ft height, rotate to VCDP, climb to HCDP at VCDP, gradually accelerate while climbing to best rate of climb speed.

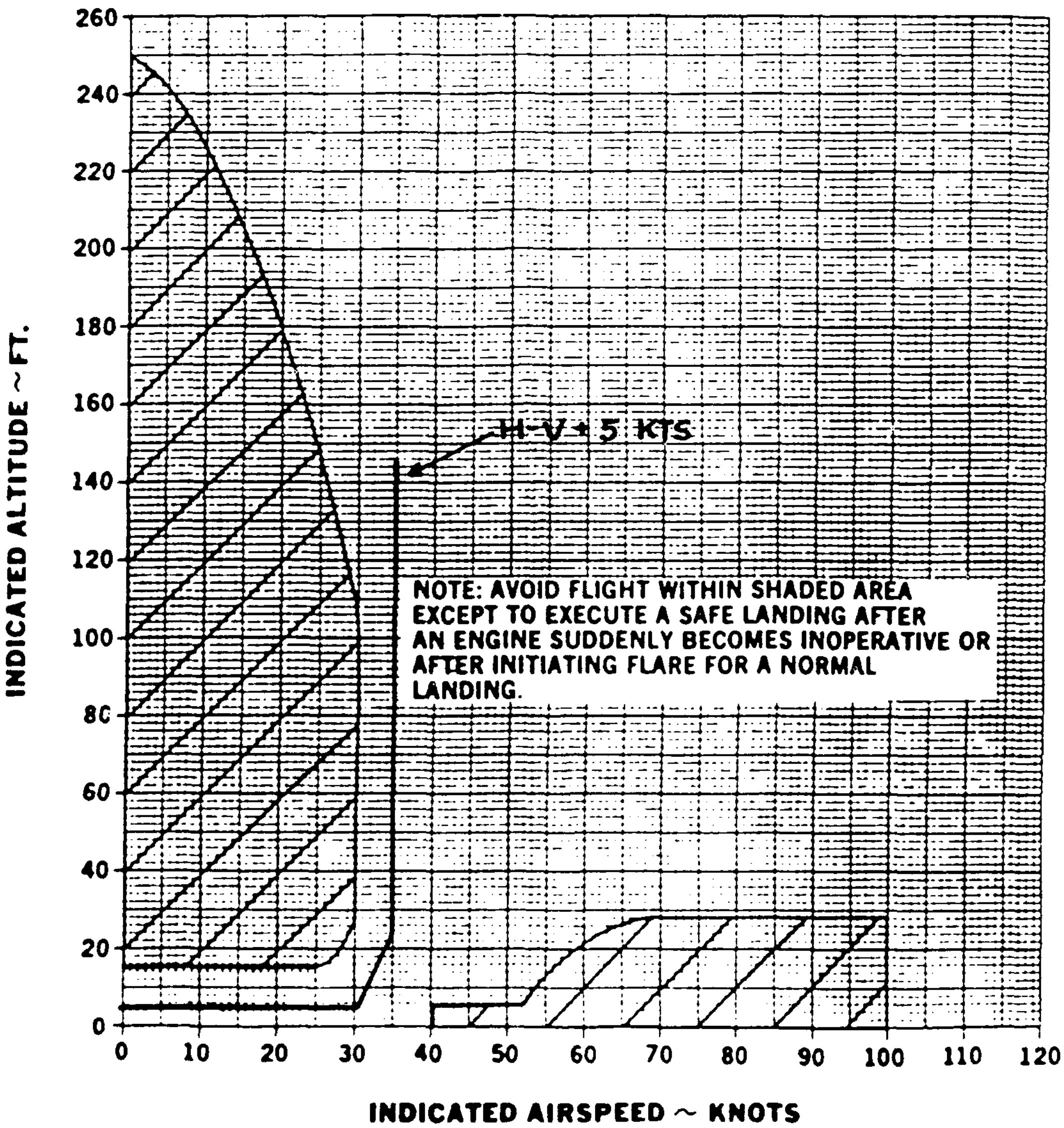


FIGURE 12. H - V + 5 KNOTS DEPARTURE PROCEDURE

initial airspeeds, approaches are initiated and intercept the desired slope sooner. Approaches flown at slower airspeeds initially overshoot the slope, delaying its interception. The NASA test data (reference 16) support this variation in characteristic approach profile shape. The airspace required to perform these approaches is dependent upon the desired approach slope flown.

The airspace required for departures is dependent upon aircraft performance and ambient conditions. Appendix B contains departure profiles for 8 aircraft at 18 combinations of gross weight, altitude and temperature. Maximum allowable weight, 85% maximum gross weight and 70% maximum gross weight were matched with standard (ISA) and hot day (ISA +20 C) temperatures and altitudes of sea level, 2000 and 4000 feet. As the departure profiles indicate, aircraft performance decreases with increases in gross weight, altitude and temperature.

The performance data for the BV 234LR, the S76A and the AS 355F were calculated by a different subcontractor than were the other five helicopters. Two assumptions used in these calculations were also different:

1) takeoff power was used instead of maximum continuous power, and

2) a maximum tip path plane of 45 degrees was used instead of 25 degrees.

These assumptions yield data that produce very similar climbout angles for airspeeds in the 40 to 60 knot range and shorter level acceleration distances below 40 knots.

An explanation of anomalies in some departure profiles follows. For MD 500E departure profiles, two hover IGE heights are used. The flight manual procedure recommends HIGE at 7.5 feet while flight manual performance data indicate HIGE at 3.5 feet. The B 206B III flight manual did not recommend a specific departure procedure so one was developed that flies the H-V+5 knots departure until reaching best rate of climb speed where a climb out is effected. The BV 234LR's maximum allowable takeoff weight is below the 85% maximum gross weight at 4000 feet pressure altitude, hot day conditions. Therefore, the 100% maximum allowable and 85% maximum gross weight profiles were not presented for these conditions. Also, BV 234LR manufacturer's recommended procedure states that "at the CDP adjust the helicopter to accelerate while climbing to best climb speed." To represent this properly on the departure graph an intercept at V_y of 100 ft. above the CDP was used. This enables the aircraft to properly accelerate while maintaining a positive climb rate.

The height-velocity diagram defines an envelope of airspeed and height above the ground from which a safe power-off or one engine inoperative (OEI) landing cannot be made. The non-existence or disappearance of an H-V diagram indicates that at the stated conditions, the aircraft is able to continue the takeoff or land safely, regardless of the point during takeoff at which an engine failure occurs. For all but two of the AS 355F gross weight, temperature and altitude combinations, the H-V diagram does not exist. A vertical departure is the "optimum" departure for those 16 cases without an H-V diagram. Half of the "optimum" departure profiles for the AS 332C are vertical departures due to the disappearance of the H-V diagram at those combinations of gross weight, altitude and temperature. Some departure profiles for the AS 332C and the MBB BO 105 CBS fall "inside" the H-V+5 knots departure profiles. This occurs because the angle of climbs are greater at airspeeds used in these procedures as compared to the H-V+5 knots procedure.

CONCLUSION

The airspace required to perform approaches is dependent upon approach slope and pilot skill more than aircraft performance. This analysis has shown not only 8:1 approach slopes to be achievable at the initial airspeeds studied, but also 7:1, 6:1 and 5:1 approach slopes. The constraints placed on aircraft in achieving approach slopes were flight manual procedures and autorotative rate of descent limits.

As evidenced by this study, minimum VMC airspace requirements are dictated by aircraft departure performance. Current flight manual departure procedures regularly violate the 8:1 FAA heliport design departure surface at the combinations of gross weight, altitude and temperature studied.

The results of this analysis are used to determine airspace requirements in "Heliport VFR Airspace Based on Helicopter Performance," DOT/FAA/RD-90/4. Rejected takeoff and one engine inoperative (OEI) capability are related to airspace requirements for heliports intended to support Category A operations in "Helicopter Rejected Takeoff Airspace Requirements," DOT/FAA/RD-90/7.

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ACRONYMS

AC	Advisory Circular
A/S	Above Slope
CAT	Category
CDP	Critical Decision Point
DOT	Department of Transportation
FAA	Federal Aviation Administration
FAATC	Federal Aviation Administration Technical Center
H-V	Height-Velocity
HAI	Helicopter Association International
HCDP	Height at Critical Decision Point
HESCOMP	Helicopter Sizing and Performance Computer Program
HIGE	Hover-In-Ground-Effect
IFR	Instrument Flight Rules
ISA	International Standard Atmosphere
KT	Knot
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
OEI	One Engine Inoperative
S/U	Slope Unachievable
SCT	Systems Control Technology, Inc.
VCDP	Velocity at Critical Decision Point
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
VNE	Never Exceed Speed

APPENDIX A
SUBCONTRACTOR SUMMARY REPORTS

FIRST SUBCONTRACTOR'S SUMMARY REPORT
(Praxis Technologies, Incorporated)

I. METHODOLOGY

This study was conducted using rotary-wing performance computer programs originally developed under contract to NASA and the U.S. Navy. Single and tandem rotor helicopter designs were analyzed using a Subcontractor modified version of HESCOMP, The Helicopter Sizing and Performance Computer Program. HESCOMP is a widely accepted sizing and performance computer program within the rotary-wing and V/STOL industry. HESCOMP has been modified to include a more accurate representation of the low-speed power characteristics, more detailed weights algorithms, center of gravity locations, advanced rotor characteristics, and maneuver analyses. Wherever possible, HESCOMP was correlated with actual flight test data from various civil and military helicopters. Because determination of the low speed powers required are critical to accurately assess takeoff and climb out capabilities, special consideration was given to the transition flight mode.

To simplify the approach to methodology assessment, the required engineering tasks were divided into seven areas: 1. geometric characteristics, 2. engine modeling, 3. airframe download, 4. drag prediction, 5. aerodynamics, 6. main and tail rotor performance, and 7. general performance. The prediction of air vehicle performance is based on an integration of these technology areas, which are separately addressed. Tasks 1-6 are external calculations which were then used as input to HESCOMP.

1. Geometric Characteristics

Accurate specification of air vehicle characteristics is essential to mathematical modeling programs, particularly to HESCOMP. The ability to provide three-dimensional helicopter data permits increased accuracy during performance analysis. The helicopters under study were physically "dissected" in order to be represented in the performance algorithms. In the case of the single rotor helicopter, the total fuselage length (in addition to the nose, tail, and constant sections) included the tail boom, the length of which, in turn, is established by the relationship between the main and tail rotors and separation distance. Additional concerns included main rotor and fuselage separation height, tail boom relative position on fuselage, center of gravity locations, lighting and gear configuration, horizontal and vertical tail relative positions, engine nacelle locations, and rotor pylon geometry. Fuselage fineness ratios, locations of maximum height and width, wetted areas, and overall length were also provided as input.

Additional considerations for the tandem rotor helicopter included rotor overlap, aft rotor pylon geometry and shaft inclination, and afterbody design.

The geometric characteristics for each helicopter under study were obtained from the appropriate corresponding flight manuals.

2. Engine Modeling

Basic turboshaft engine performance is determined through non-dimensionalized parameters as a function of Mach number versus turbine inlet temperature, T4.1. Referred engine parameters include horsepower, fuel flow, gas generator speed, and power turbine speed. Engine ratings from ground idle to maximum or contingency power setting are indicated. Non-dimensionalized engine shaft horsepower available and associated fuel flow are functions of the maximum static sea level installed power and ambient pressure and temperature ratios. Non-dimensionalized gas generator and power turbine speeds are functions of temperature ratio. Because of the normalized, referred format, all engine data are valid for any ambient condition, whether standard or nonstandard. With the exception of referred power, none of the engine parameters are dependent upon power turbine speed.

Manufacturer's data on some engines show significant variations in both referred power and lapse rate with respect to changes in altitude. These variations are due to Reynold's number effects. It has been found that these effects can be accounted for by means of a multiplicative factor on power available, which is a function of the Reynold's number based on compressor inlet conditions, compressor blade geometry, and tip speed.

It is imperative to have an accurate prediction of the engine power available when computing performance parameters. Engine certificated specifications were used for each configuration when available. Parameters that reduce engine power available to the rotor include appropriate engine inlet and exhaust losses and accessory horsepower extraction.

3. Airframe Download

Download is due to the presence of the airframe in the rotor downwash. Download affects the performance ability of the helicopter anytime the rotor downwash impinges on the airframe, such as in hover and very low-speed flight. As an example, in order to hover, the rotor must produce enough thrust to equal the weight of the vehicle plus the download. Typical values of the helicopter thrust-to-weight ratios are between 1.03 and 1.05. A semi-empirical method was used for estimating download yielded correlation within ten percent for most of the available data. Airframe shape, perimeter area, and vertical location under rotor were strip calculated as a function of fuselage station. Correspondingly, the rotor wake contraction and dynamic pressure were also strip calculated. The strip calculations were used to obtain the total airframe download.

4. Drag Prediction

The total minimum profile drag is estimated using a detailed skin friction and pressure drag calculation based on empirical trends. The skin friction drag was obtained by computing the skin friction drag of a flat plate as a function of Reynold's number, Mach number, and surface roughness, and then correcting the drag for three-dimensional effects. Pressure drag was computed using empirical equations defined as a function of fineness ratio and the chordwise location of the maximum thickness. Wherever possible, drag estimates were correlated with any published data from the airframe manufacturers. Detailed drag estimates for each airframe component were calculated and then summed to provide total minimum drag.

5. Aerodynamics

Aerodynamics of the fuselage and horizontal and vertical tail surfaces were determined for trimmed flight conditions. Aerodynamic contribution of the vertical tail is important in determining the tail rotor thrust requirements for anti-torque. The horizontal tail, if present, provides fuselage pitch attitude in trim conditions. Both tail surface contributions are dependent upon lift and drag coefficients, pitch or yaw angle, surface area, and longitudinal and lateral locations in reference to fuselage.

6. Main and Tail Rotor Performance

The calculation of the total contributions of thrust and propulsive force from both the main and tail rotor systems are critical in predicting helicopter performance. Main rotor performance was calculated using a combination of momentum theory and empirical corrections. Main and tail rotor performance was correlated with manufacturer supplied data for the hover and minimum power required points. Total shaft horsepower required is dependent upon airfoil type, platform shape, blade number, twist, cutout, trim conditions, and gearbox efficiency. For single rotor helicopters, tail rotor parameters were also included. Typically, the four elements of main rotor power required are:

1. Induced Power - power required to generate lift.
2. Profile Power - power required to turn the rotor.
3. Parasite Power - power required to supply propulsive thrust in forward flight.
4. Nonuniform Downwash Power - power correction due to nonuniform inflow and downwash effects in forward flight.

Tail rotor power required was calculated as a function of the main rotor power required, the tail rotor arm length, vertical fin blockage and effectiveness, and tail rotor aerodynamics.

Rotor power prediction has traditionally been associated with hover and forward flight conditions. Transition powers from hover to minimum power speeds are difficult to analyze. Within published literature, helicopter performance data has been measured at hover and in forward flight at airspeeds from just below the airspeed for minimum power out to the maximum airspeed attainable. Climb performance is usually measured at the airspeed for best rate of climb (approximately the same airspeed as for minimum power required), and frequently, at the hover, or zero airspeed, condition. Generally, no data are taken for the transition airspeed range between hover and minimum power airspeed. For certain performance conditions, the low speed transition corridor is vital to helicopter operations. Most helicopters operate in the transition regime for a brief period of time, constituting takeoff to climb out, or coming in for a landing. When a helicopter had sufficient power to hover, it usually had enough power to pass safely through transition.

Methodology to accurately predict the transition regime is non-existent. Neither the simple momentum analysis used at hover, nor the fixed wing analogy commonly used for forward flight is valid. A simplification of the rotor induced power in forward flight results from assuming a zero rotor angle of attack. Assuming a rotor ellipitical lift distribution in cruise flight implies a uniform induced rotor downwash over the rotor disk. This downwash is small compared to the forward flight airspeed. However, as the helicopter's airspeed is reduced from cruise into the transition regime, the rotor induced downwash becomes a significant portion of the flight airspeed, and increasingly non-uniform. This implies that the classical forward flight equation assumptions are not necessarily valid for predicting the transition powers required.

To obtain a reasonable estimation of power required at very low advance ratios where neither normal cruise nor hover rotor characteristics totally describe the operating environment of the rotor, HESCOMP uses an empirical fairing technique. This method is based on a contracted induced wake angle coupled with algorithms which insure a smooth transition between hover and cruise. For this study, a correlation of HESCOMP-type methodology with flight test data obtained from Edwards Air Force base for a variety of military helicopters was also used. This database provides a statistical method of correlating the prediction of transition power required based solely on inputs of hover and minimum powers required. The predictive methodology used was well within ten percent of the actual flight test data.

7. General Performance

Tasks 1 through 6 establish the mathematical algorithms necessary for input to HESCOMP. This task consisted of using HESCOMP as a general performance tool which provided powers available and required to perform a variety of mission requirements. Among the output from HESCOMP were flight path angles and airspeeds for climb performance, and engine and rotor performance for accelerations and takeoff distance calculations. Acceleration data were computed outside of HESCOMP. Time to program was considered and an estimated cost savings was achieved by not linking the acceleration algorithms inside the main HESCOMP program.

II. ASSUMPTIONS

Several assumptions were required in the prediction of civil aviation helicopter performance. Eight helicopter configurations were examined of which five vehicles were multi-engine. The following assumptions apply:

1. Engine power available was assumed to collapse as the inverse function of both pressure ratio and square root of the temperature ratio.

2. Longitudinal acceleration data were generated at maximum power available or takeoff power.

3. Rate of climb data were generated at intermediate rated power or 30 minute power rating.

4. Gearbox torque limits were applied as indicated by the flight manuals.

5. Vertical rate of climb efficiencies were held constant for each configuration.

6. Transmission efficiencies were held constant at 97 percent.

7. Accessory horsepower extraction was estimated based on the installed avionics and held constant as a function of airspeed.

8. Rotor RPM was held constant at 100 percent.

9. One Engine Inoperative (OEI) powers required at hover and forward airspeeds were assumed to be the same as all engines operating.

III. MANUFACTURER DATA USED

In order to accurately model the powers required and available throughout the low speed transitional flight regime, specific manufacturers' data were used. Powers available and required for hover and minimum power flight speed for steady state level flight was requested. Also, the vertical rate of climb at hover and the steady state rate of climb at a given airspeed was requested. However, not all data was supplied from the manufacturers, decreasing the accuracy of performance prediction. Otherwise, performance predictions are estimated to be within ten percent of the flight test data.

The following data were supplied by manufacturers and used accordingly:

NOTE: All rates of climb are in feet per minute.

GW	=	vehicle gross weight (lb) used for matching powers and climb rate
HPavl	=	maximum engine horsepower available
Qlmt	=	engine torque limit as percentage of sea level engine power available
HPmin	=	minimum horsepower required to maintain level flight
Vmin	=	true airspeed (knots) corresponding to HPmin
HPhov	=	horsepower required for hover
froc	=	forward rate of climb at Vcl
Vcl	=	horizontal airspeed (knots) corresponding to froc

1. Enstrom F 28F

GW	=	2,600
HPavl	=	225
Qlmt	=	N/A
HPmin	=	126 at 2,350 lb
Vmin	=	50
HPhov	=	245
froc	=	1,440 at 2,350 lb
Vcl	=	50

2. McDonnell Douglas 500E

GW	=	3,000
HPavl	=	420
Qlmt	=	N/A
HPmin	=	139 at 2,100 lb
Vmin	=	50
HPhov	=	332
froc	=	1,875 at 375 HP
Vcl	=	50

3. Bell 206B III

GW	=	3,200
HPavl	=	420
Qlmt	=	N/A
HPmin	=	158
Vmin	=	50
HPhov	=	300
froc	=	1,186
Vcl	=	50

4. Aerospatiale AS 355F

GW	=	5,071
HPavl	=	840
Qlmt	=	N/A
HPmin	=	323
Vmin	=	55
HPhov	=	564
froc	=	1,856
Vcl	=	55

5. MBB BO 105 CBS

GW	=	5,271
HPavl	=	840
Qlmt	=	86%
HPmin	=	314
Vmin	=	65
HPhov	=	550
froc	=	1,461
Vcl	=	65

6. Sikorsky S 76A

GW	=	10,500
HPavl	=	1,300
Qlmt	=	N/A
HPmin	=	564
Vmin	=	75
HPhov	=	1,242
froc	=	1,491
Vcl	=	75

7. Aerospatiale AS 332C

GW	=	18,959
HPavl	=	3,322
Qlmt	=	90%
HPmin	=	1,293
Vmin	=	75
HPhov	=	2,599
froc	=	1,772
Vcl	=	75

8. Boeing Vertol 234 LR

GW	=	48,500
HPavl	=	8,707
Qlmt	=	N/A
HPmin	=	3,933
Vmin	=	90
HPhov	=	6,533
froc	=	2,545
Vcl	=	90

IV. CONCLUSIONS

The development of the analytical models proved to be a greater effort than estimated due to the difficulty encountered in matching the computational data with the flight manual data. Matching manufacturer-supplied data (when provided) with computational data (horsepower required and corresponding rate of climb for a given true airspeed) was straight-forward. Manufacturer's estimates of horsepower extraction to drive accessories and transmission gearbox efficiency would have been helpful in developing the models.

Information available in each specific helicopter flight manual was used to collapse the data for different ambient conditions. Flight manual data were used to provide a first estimate while waiting for more specific data to be supplied from the manufacturers. Most flight manual data introduced ten percent error just in graph plot interpretation. This error is magnified when collapsing the data for density altitude. When manufacturers' data were supplied, results changed. The data received from most manufacturers usually included several different ambient conditions, enabling a much more accurate, and simplified, approach. The flight manual is required for helicopter definition and operating procedures but should not be used for performance matching with the analytical model, unless a lower accuracy than 10% is acceptable.

Vertical rate of climb was not supplied in most flight manuals nor by many of the manufacturers. This data would be very useful in estimating hover and very low speed rate of climb performance. Helicopters have different vertical drags which are difficult to accurately estimate. Vertical drag affects the vertical climb power required used to determine the vertical rate of climb. Without a good vertical drag estimate, an accurate vertical rate of climb is difficult to predict.

Realizing that data recorded during FAA flight qualification are limited, when used the data should be able to yield preliminary estimates of low speed performance. These additional data would enhance the accuracy of the low speed performance estimates. However, the effectiveness of increased accuracy above the level presented for this type of study is questionable.

SECOND SUBCONTRACTOR'S SUMMARY REPORT
(University of Maryland, Aeronautical Engineering Department)

I. INTRODUCTION

This study was completed using HESCOMP (Helicopter Sizing and Performance Computer program) to determine the power required, rate of climb (ROC) and angle of climb (AOC) at the various weights, altitudes, and ambient conditions. The take-off and normal rated powers available for each of the aircraft were determined from the data supplied by SCT. The acceleration distance and time were calculated using an external proprietary program written in "C".

II. ACCELERATION DISTANCES AND TIMES

These data were determined by numerically integrating the acceleration capabilities of the aircraft. The acceleration capabilities are a function of the operating gross weight of the aircraft, the ambient conditions, power available, rotor system design, inertial loadings, and the operational procedures (control and attitude limitations, IGE, OGE, etc).

The response of the rotor system to the control changes associated with the transition from hover to forward acceleration is represented by an exponential function with an assumed time constant of one second. This time constant accounts for the delay associated with the thrust change required by the rotor system, thus disallowing instantaneous thrust changes within the rotor system.

The acceleration capabilities of each helicopter were estimated using semi-empirical methods previously developed from an extensive database. These data represent airborne acceleration capabilities and do not represent ground runs with the associated landing gear coefficients of friction. This limitation requires the aircraft to have the ability to hover (i.e., airborne or at minimum in-ground-effect) at the specific operating condition.

The airborne acceleration data are determined through scaling of semi-empirical data. The scaling requires knowledge of the maximum hover weight capability of the aircraft at the operating ambient condition, the operational weight of the aircraft, and the maximum speed of the aircraft at the operating ambient and weight.

Because of the limited scope of this study, it is imperative to understand the analytical procedure used to calculate the distance and time associated to accelerate to a given airspeed. In conversations with Praxis Technologies personnel regarding their original approach to this problem it was determined that they undertook a more rigorous analyses. In the Praxis Technologies approach they determined maximum overall acceleration accounting for ground run where more favorable. Also, in the original study the maximum thrust capability of the aircraft was used to determine the propulsive capability with tip-path plane tilt limited to 25 degrees. The ratio of the horizontal thrust less drag, to the weight of the helicopter was used to determine the acceleration. If the power available was insufficient for IGE hover at a given condition, they calculated the acceleration of the aircraft in a ground run before achieving flight. It was found that it was sometimes beneficial to keep the aircraft on the ground regardless of the power required at certain conditions in order to gain enough speed to pull-up quickly once achieving high speed.

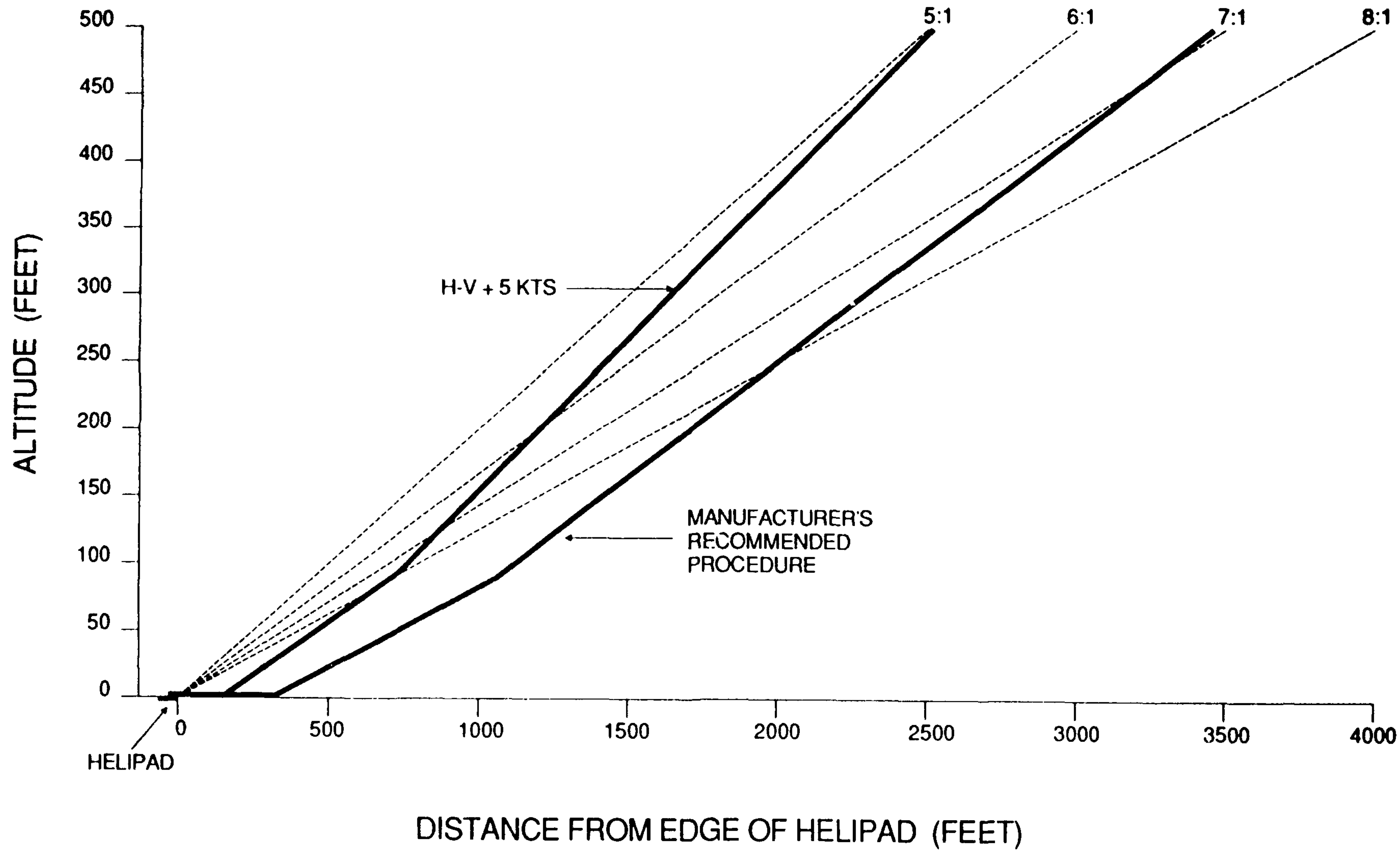
There are several variables that must be accounted for when determining take-off procedures. When ground runs are involved, the acceleration capabilities are different than with airborne conditions, and would provide an inconsistent comparison with data provided at weights where at minimum hover IGE is achievable. Therefore, a consistent takeoff procedure must be established to allow comparison of acceleration distances and times. The consistency within the data provided has been established by requiring airborne flight acceleration capability. No attempt was made to determine the trade-off between a ground run and airborne IGE flight due to the limited scope of this study.

In the case where the aircraft was not power limited and the Praxis Technologies study included a ground run, a difference in the acceleration distance and time would be expected. The data supplied by our approach would probably be somewhat more optimistic than the Praxis data up to maybe 40 or 50 knots and less optimistic at higher speeds depending on the take-off conditions. The reason for this is that during a ground run the aircraft has to overcome significant frictional forces at low speeds, but will accelerate very quickly once this is achieved. Output data from HESCOMP can be matched to the flight test data supplied for each aircraft by a variety of combinations of input. A match was made to the ROC data supplied in all cases. All other data, if supplied by SCT, was also matched.

APPENDIX B
DEPARTURE PROFILES

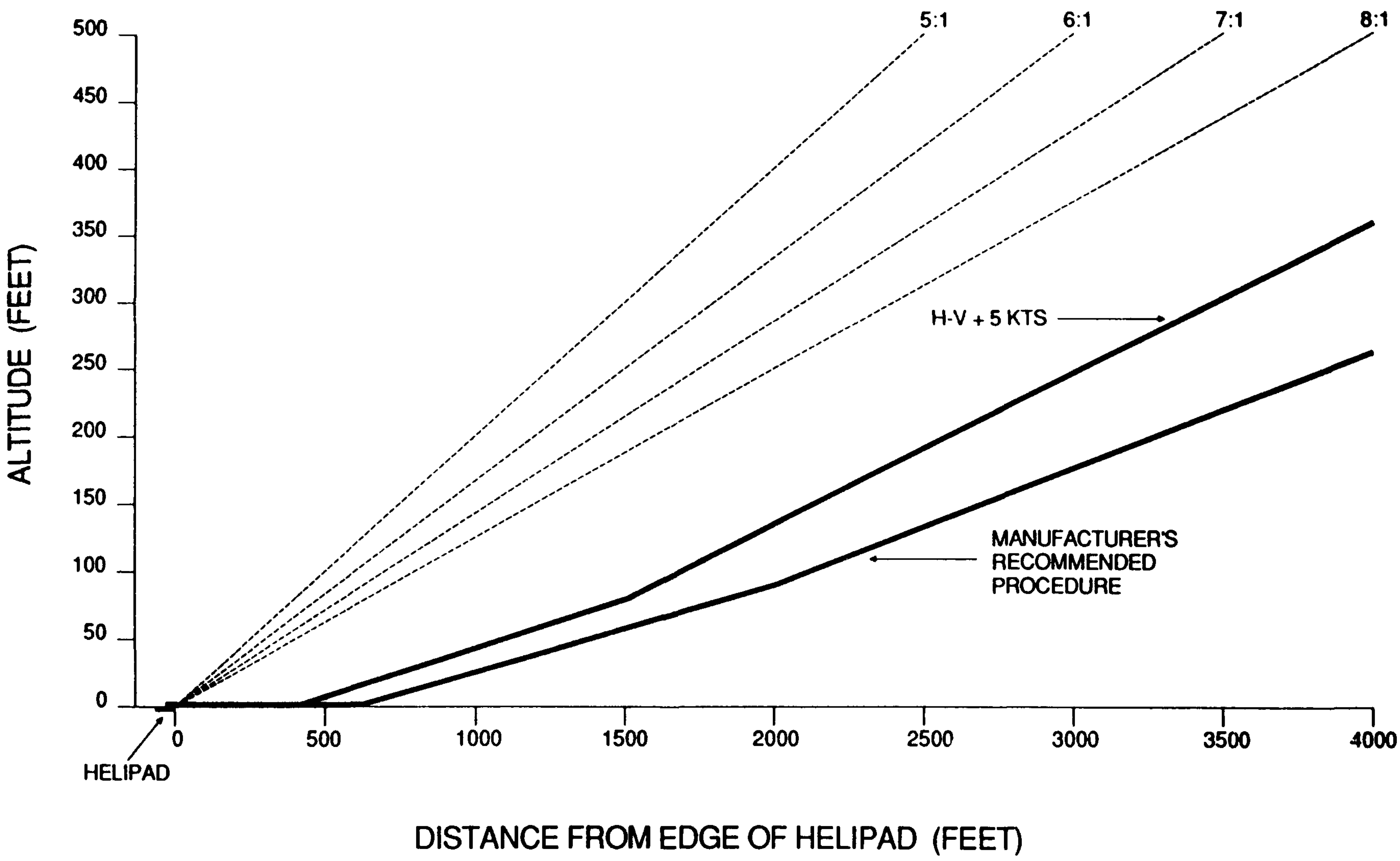
F 28F DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, STANDARD DAY



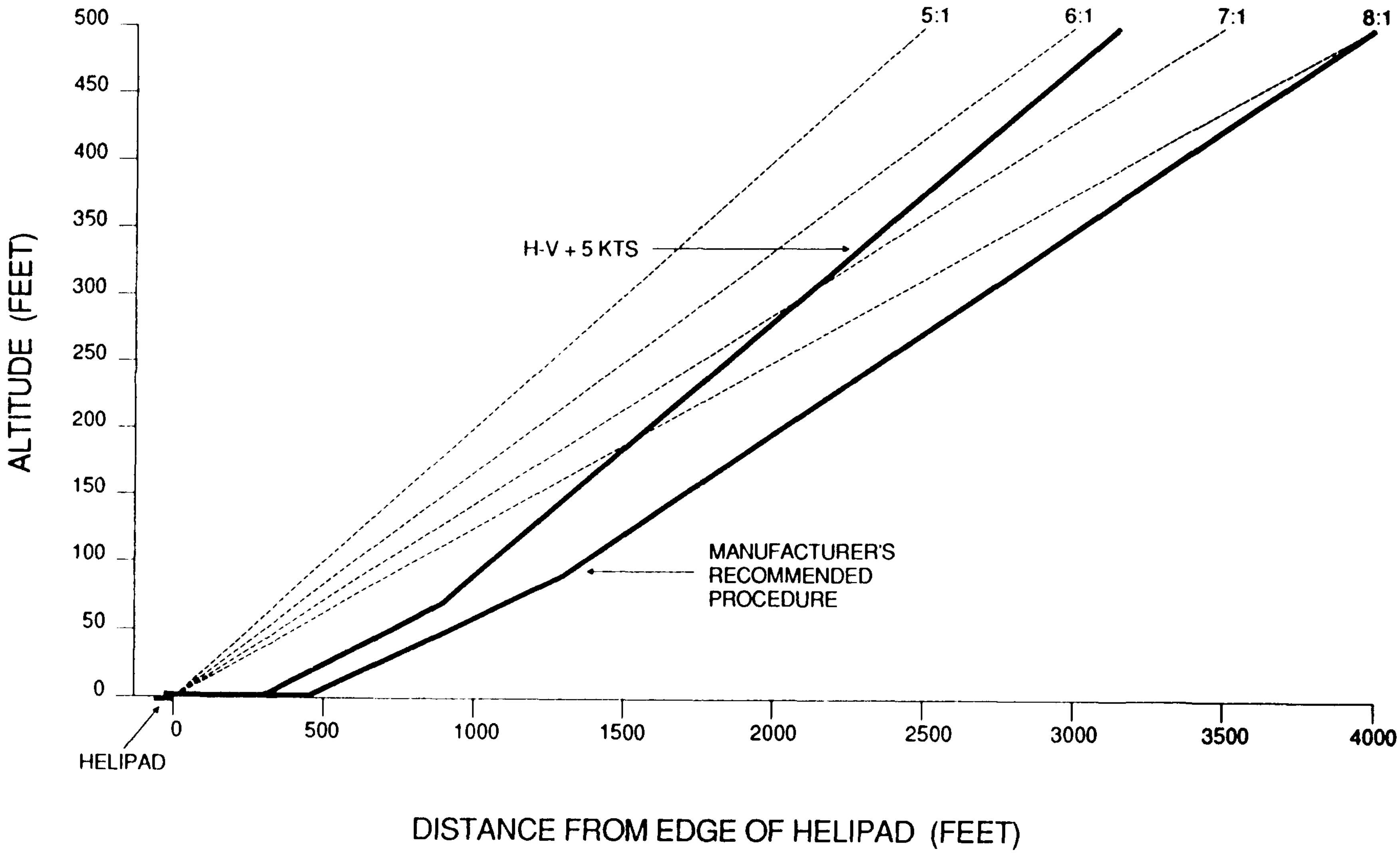
F 28F DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, HOT DAY



F 28F DEPARTURE PROFILES

MAX. G.W., 2000 FEET, STANDARD DAY



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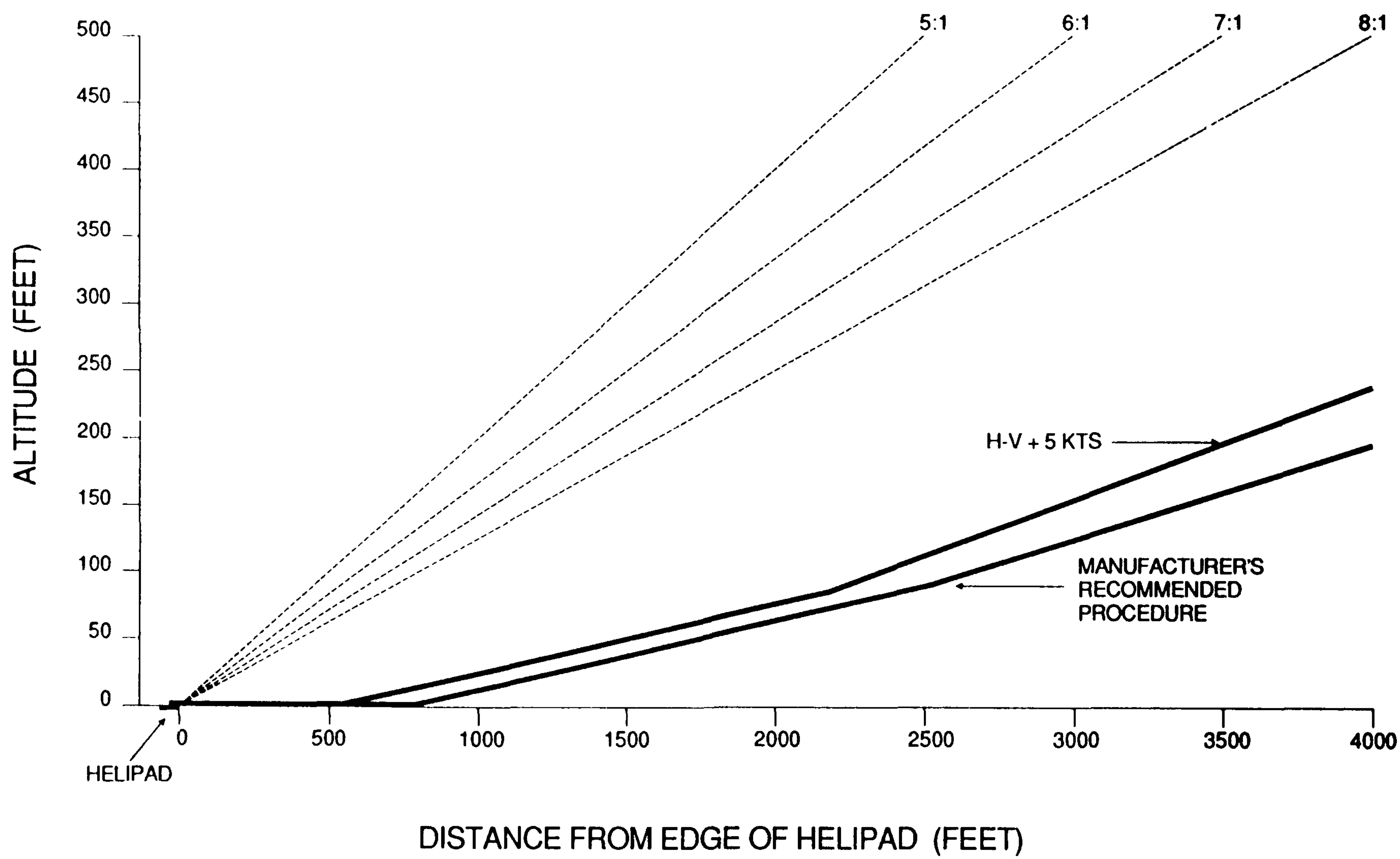

F 28F DEPARTURE PROFILES

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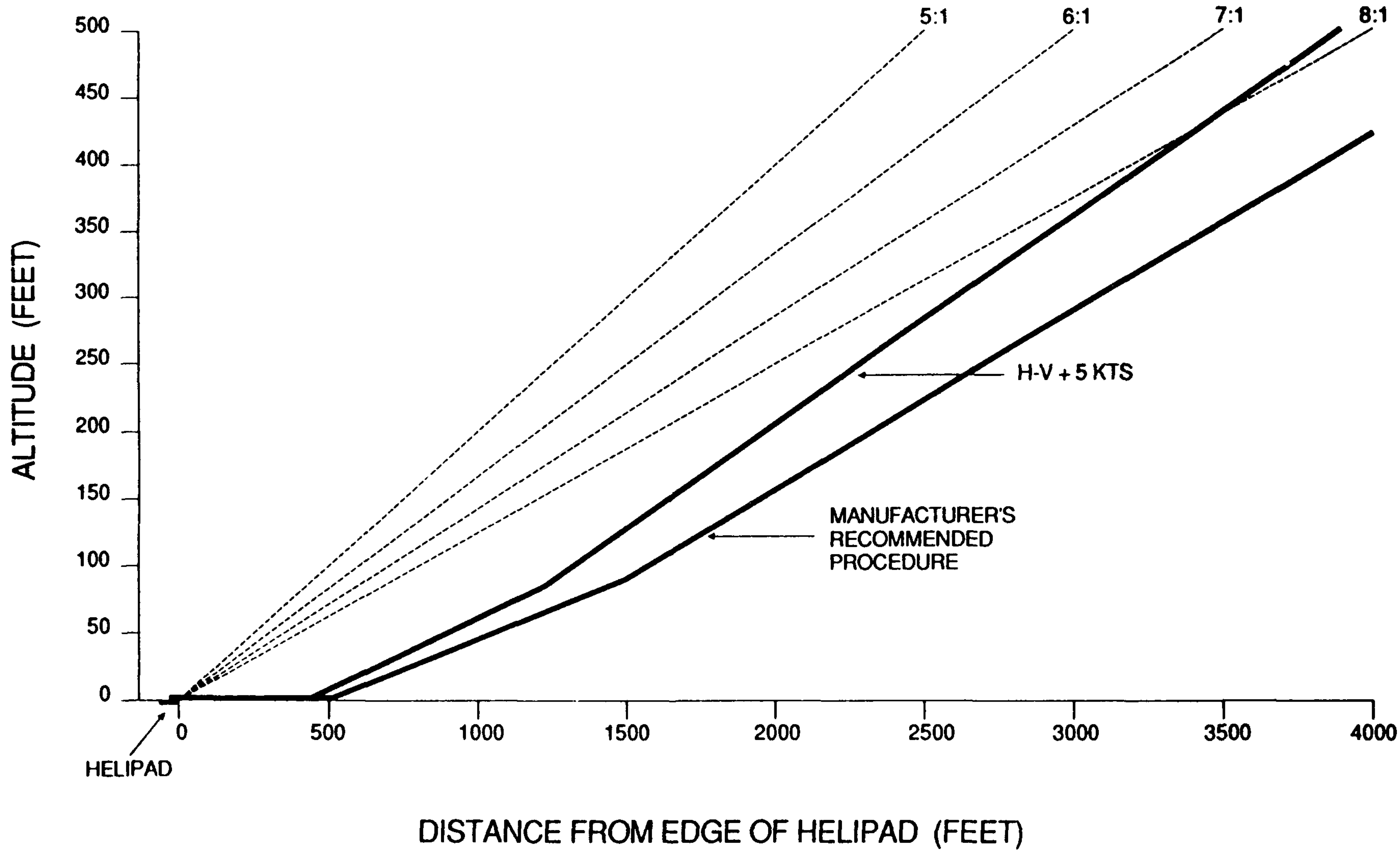

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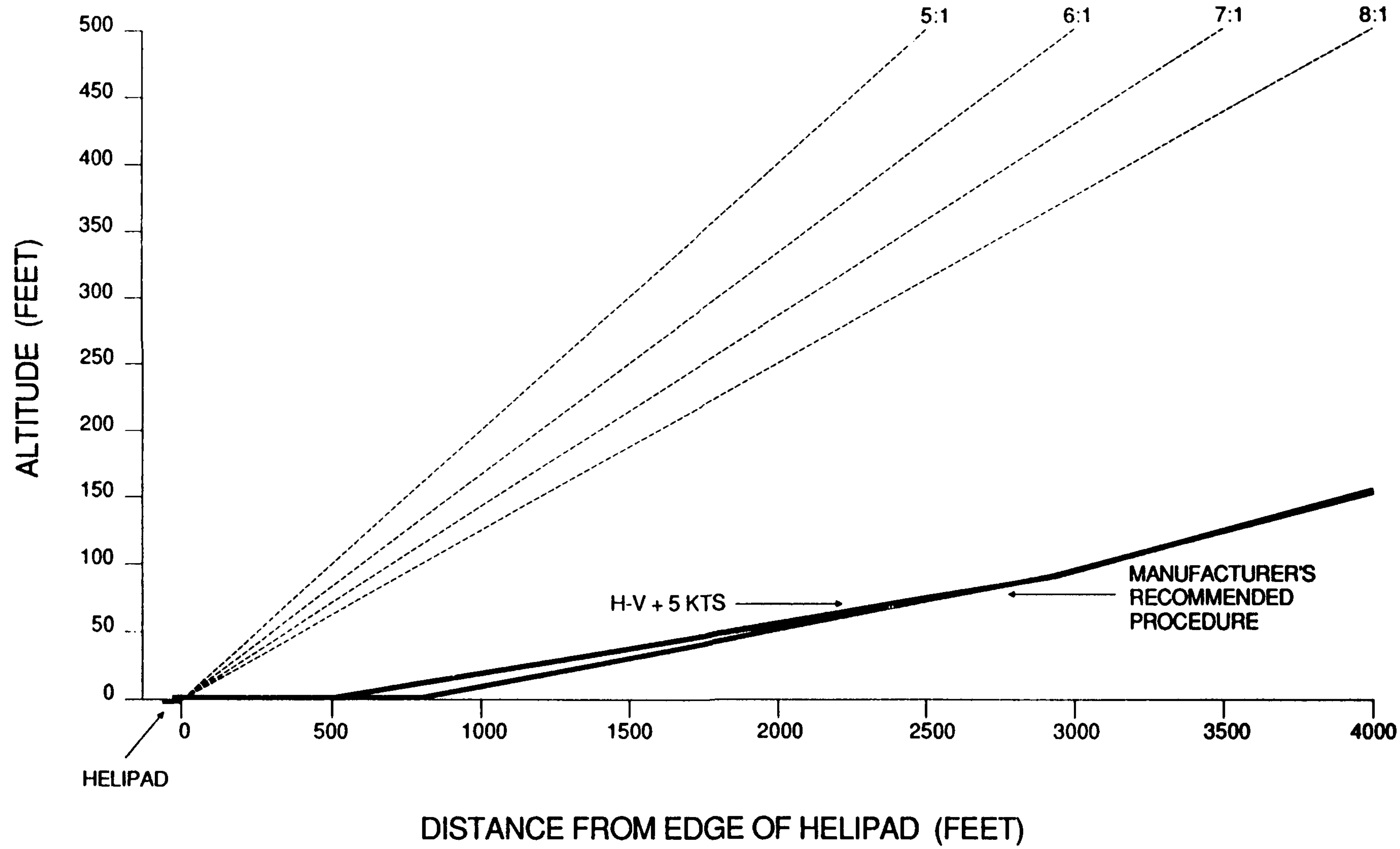
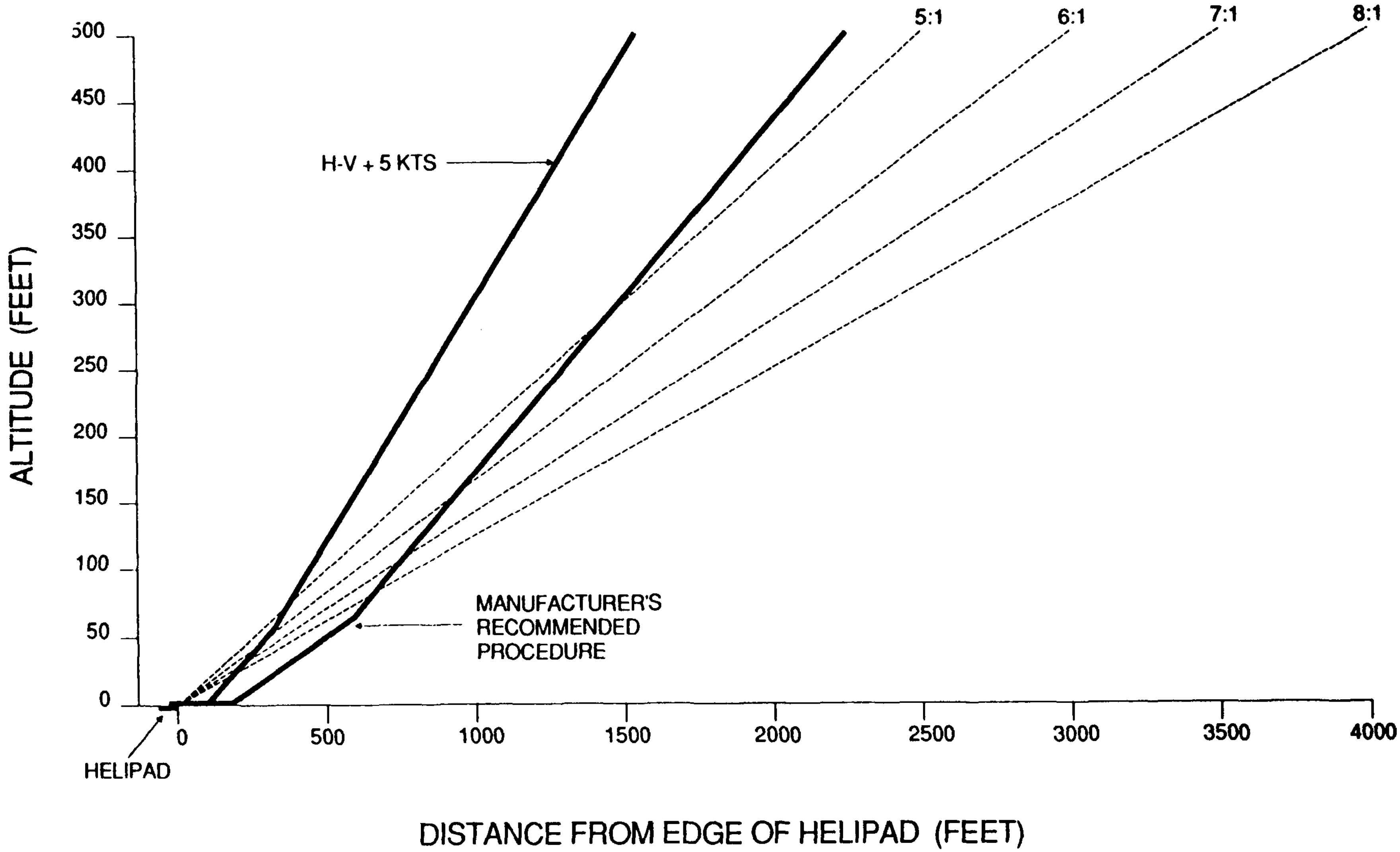


F 28F DEPARTURE PROFILES

85% MAX. G.W., SEA LEVEL, STANDARD DAY



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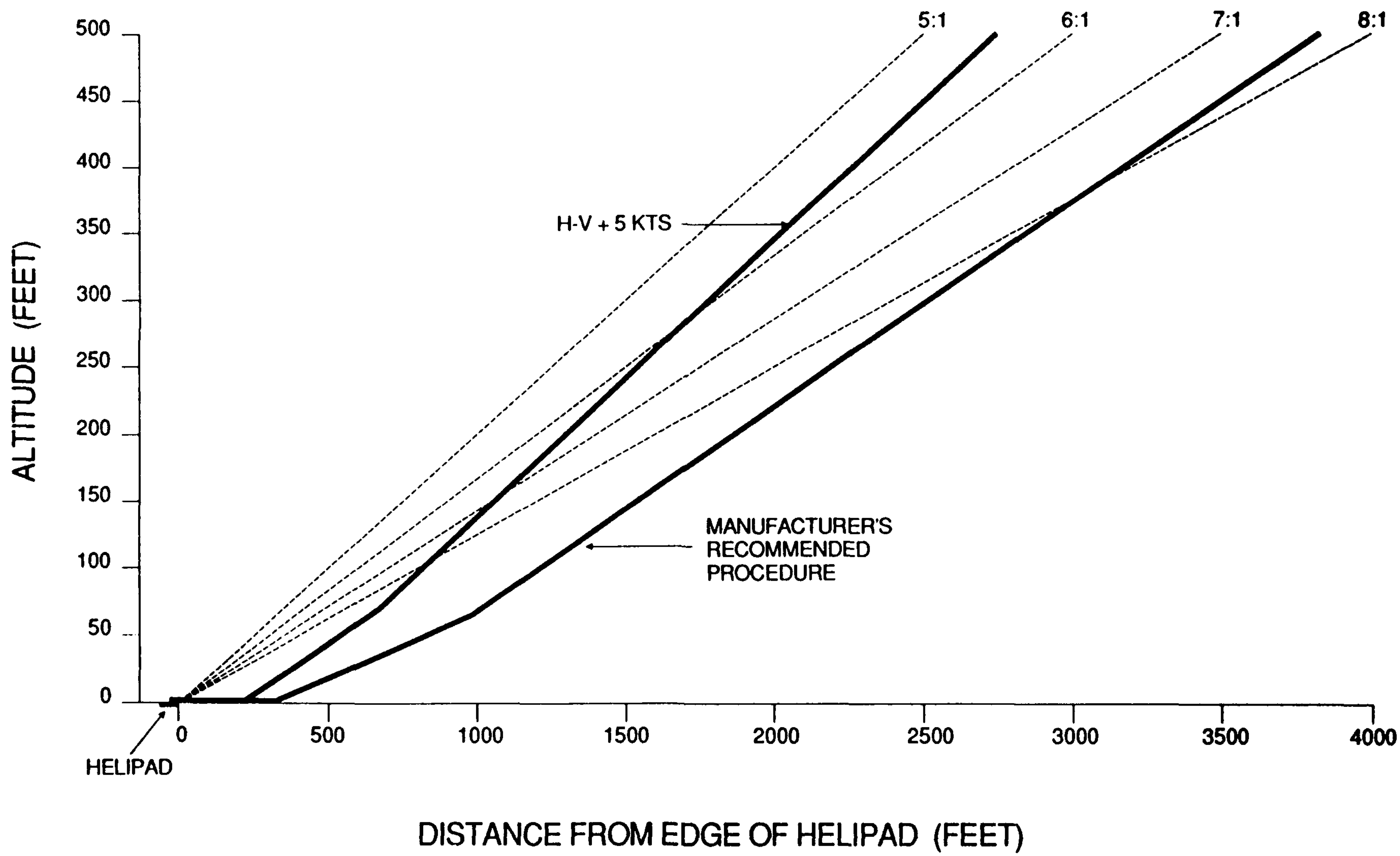

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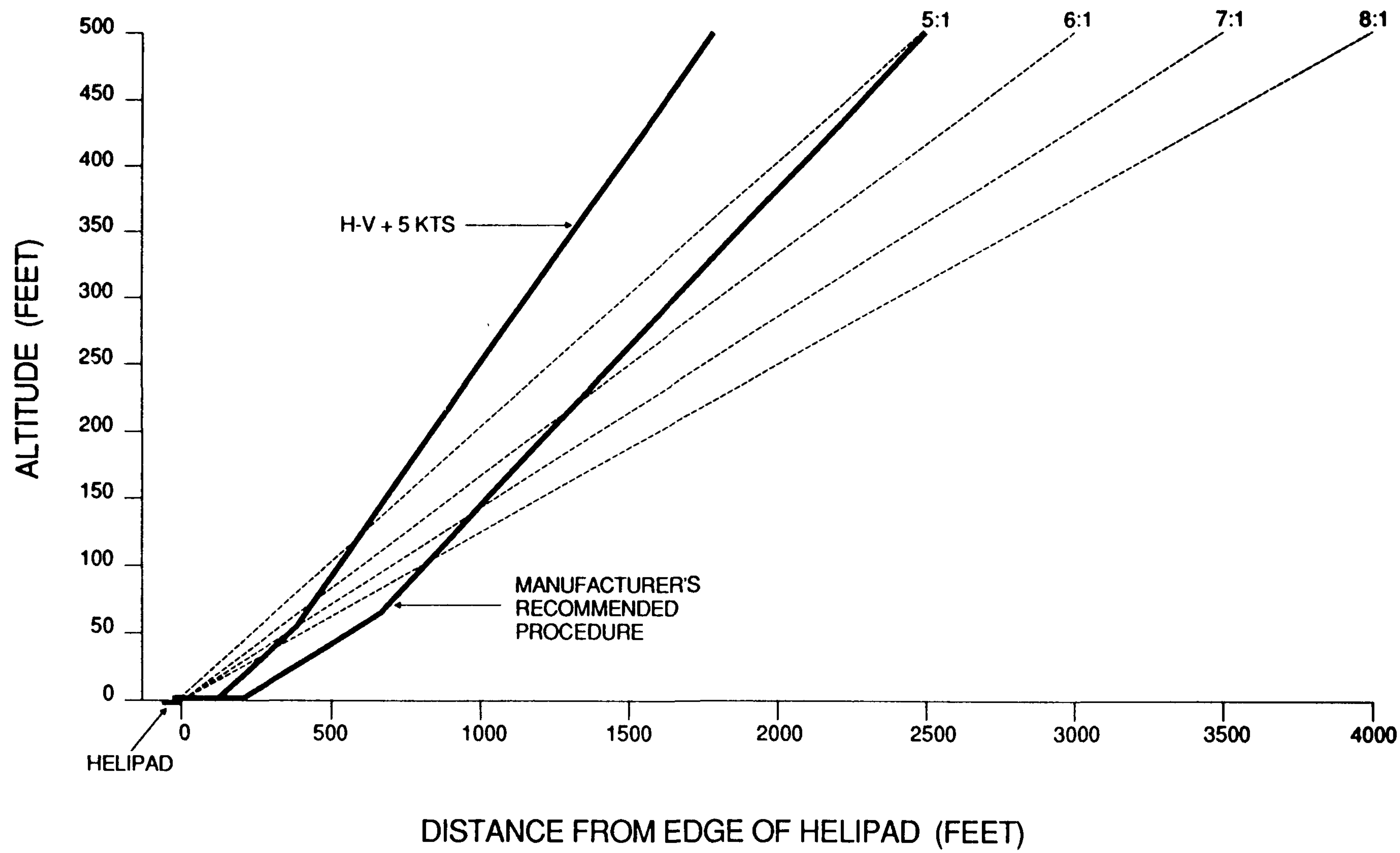

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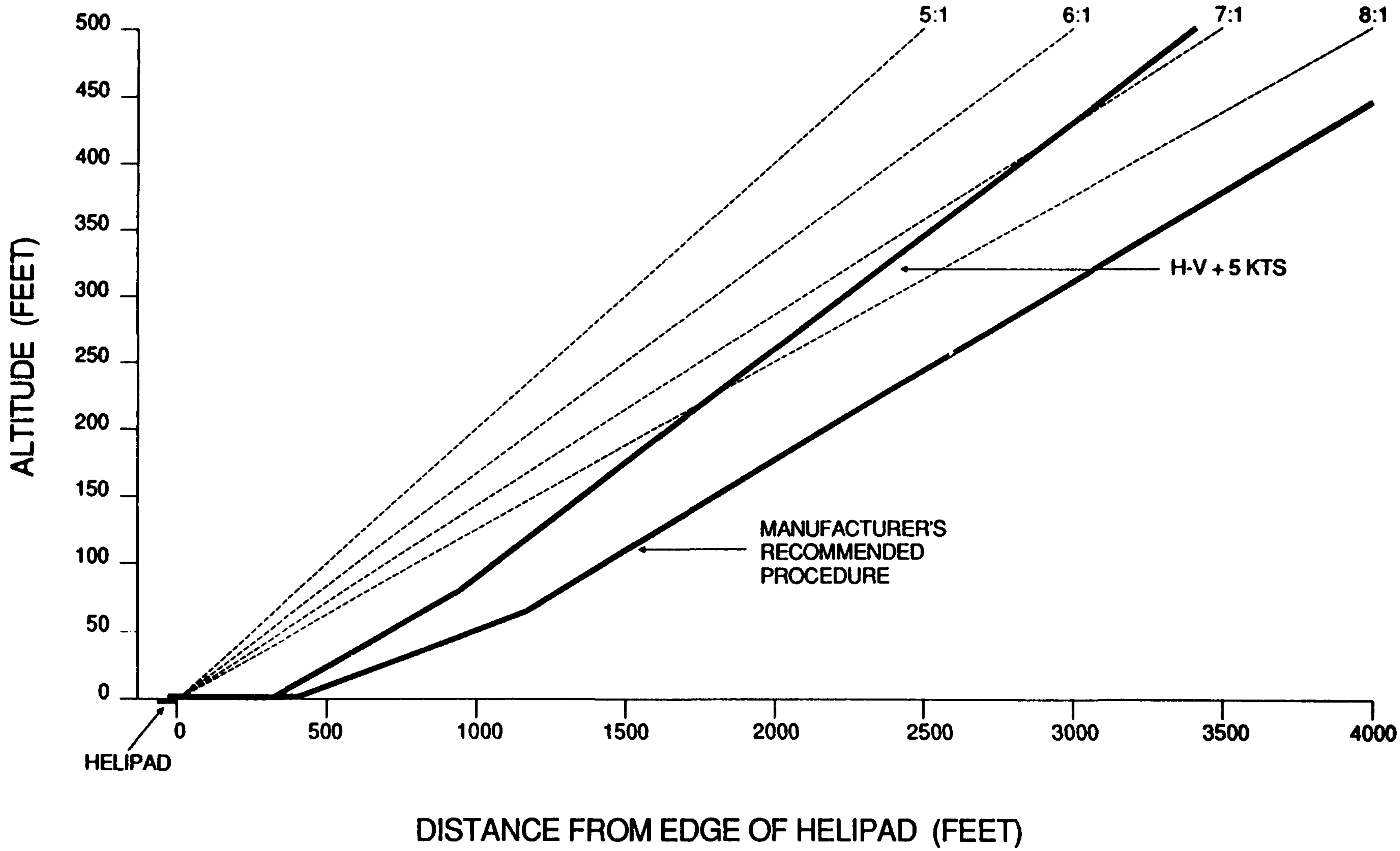

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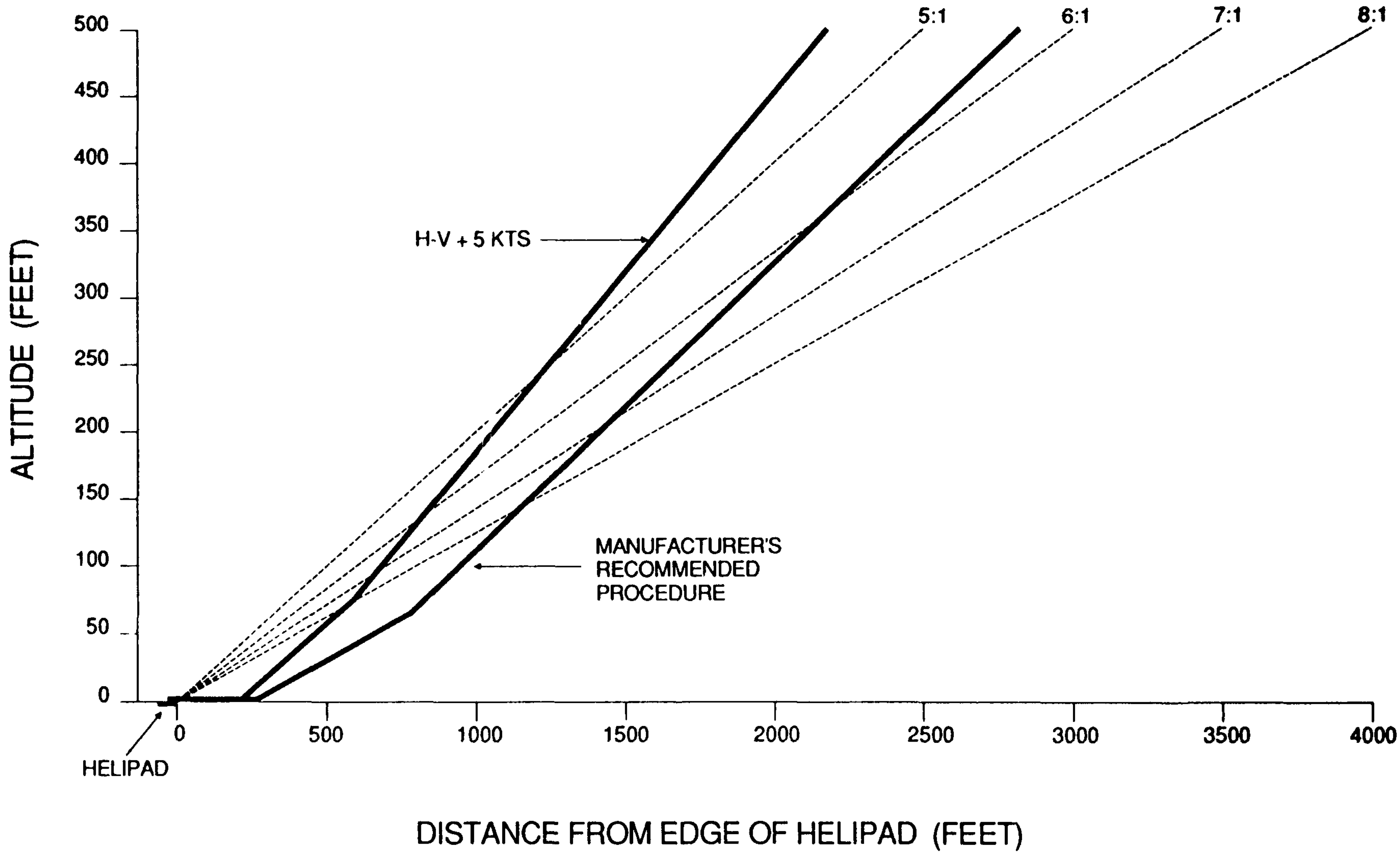

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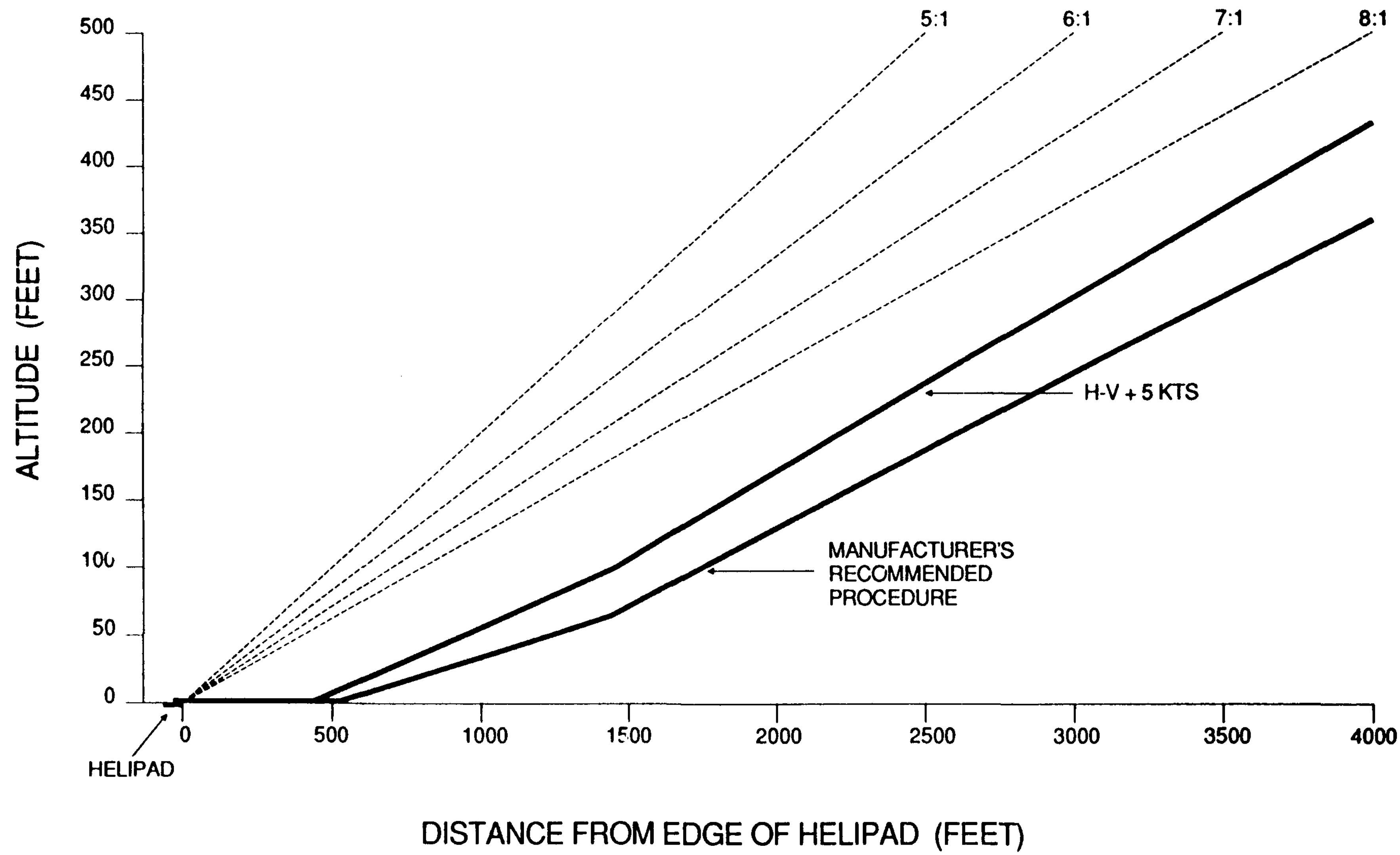

F 28F DEPARTURE PROFILES

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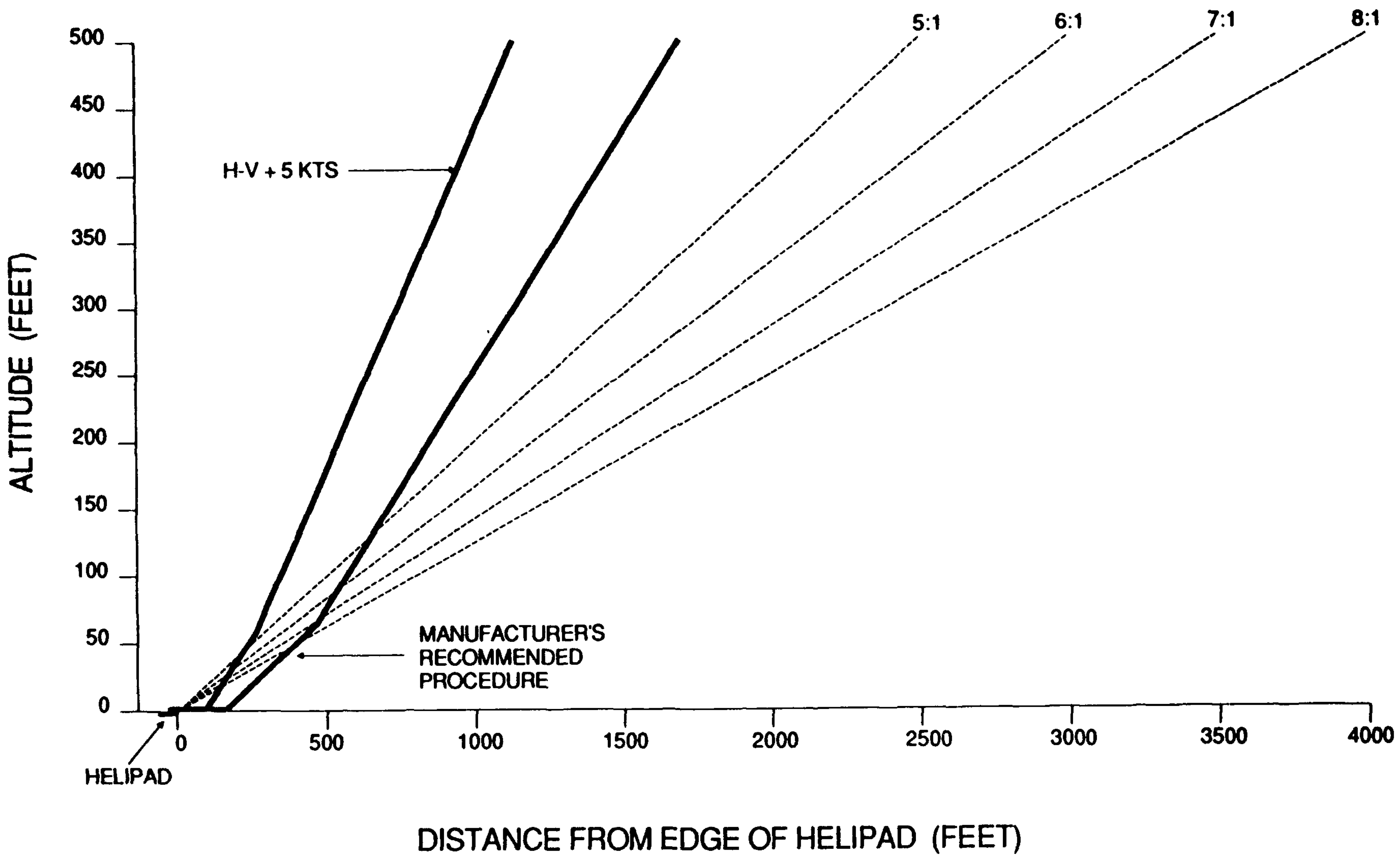

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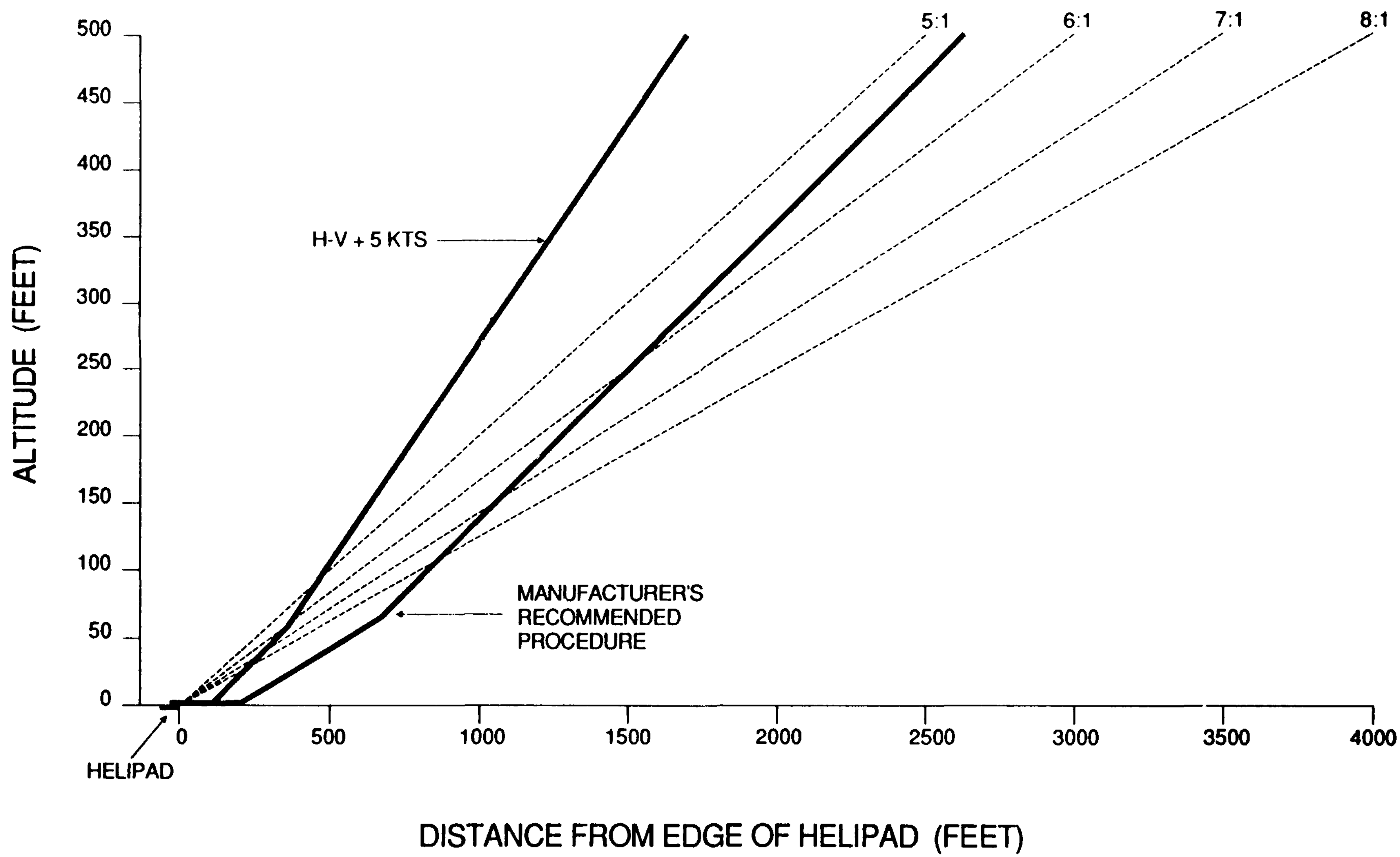

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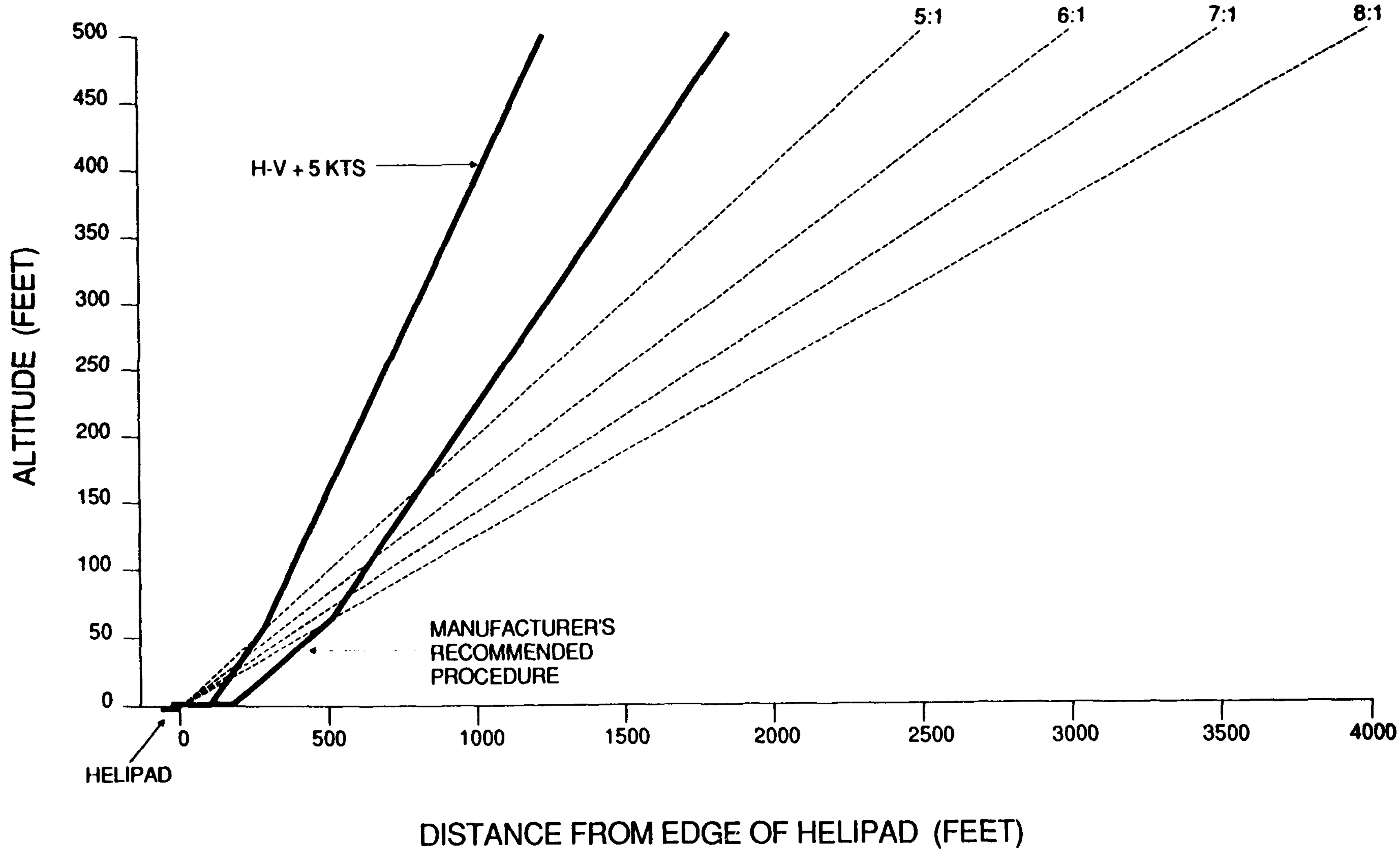

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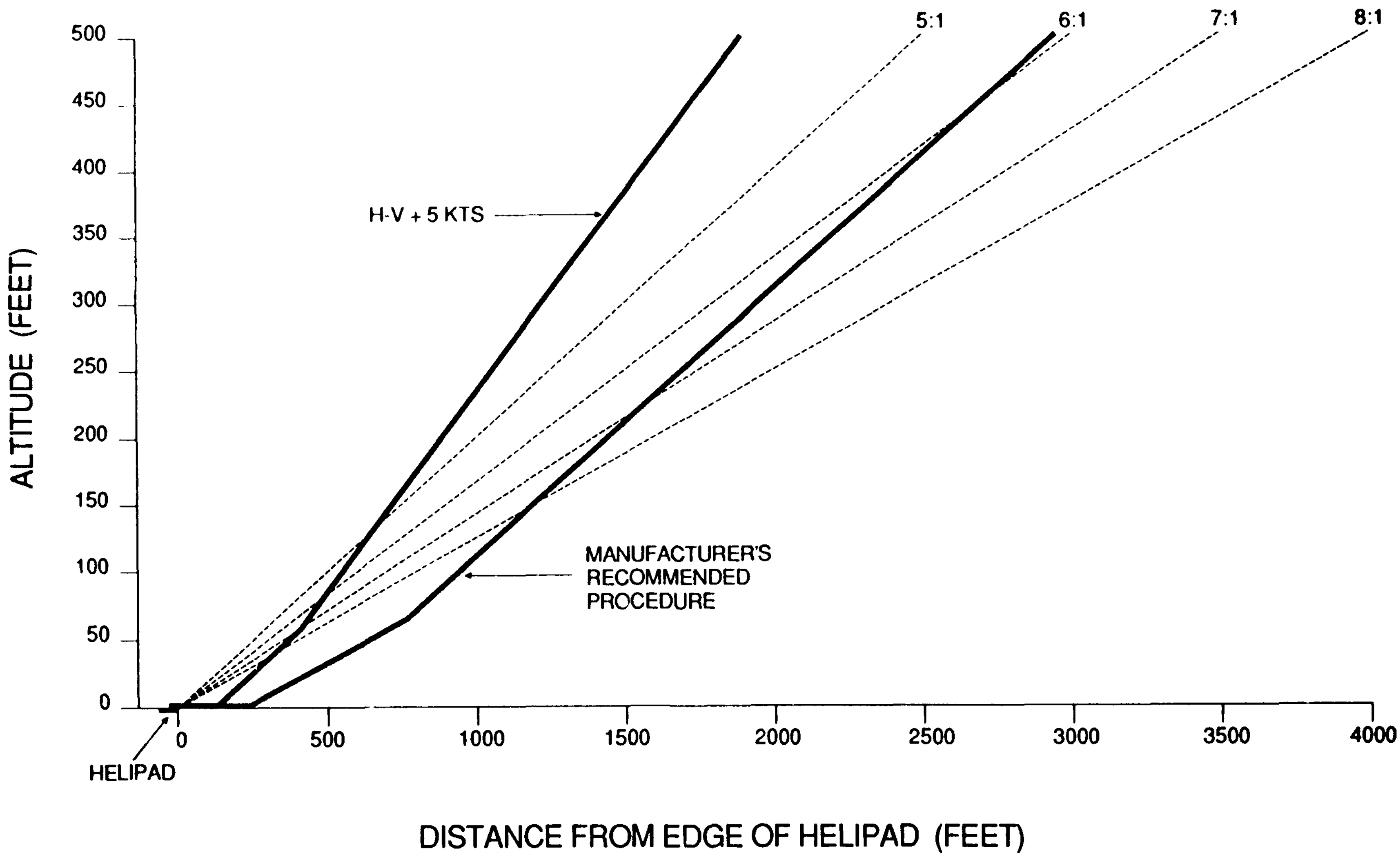

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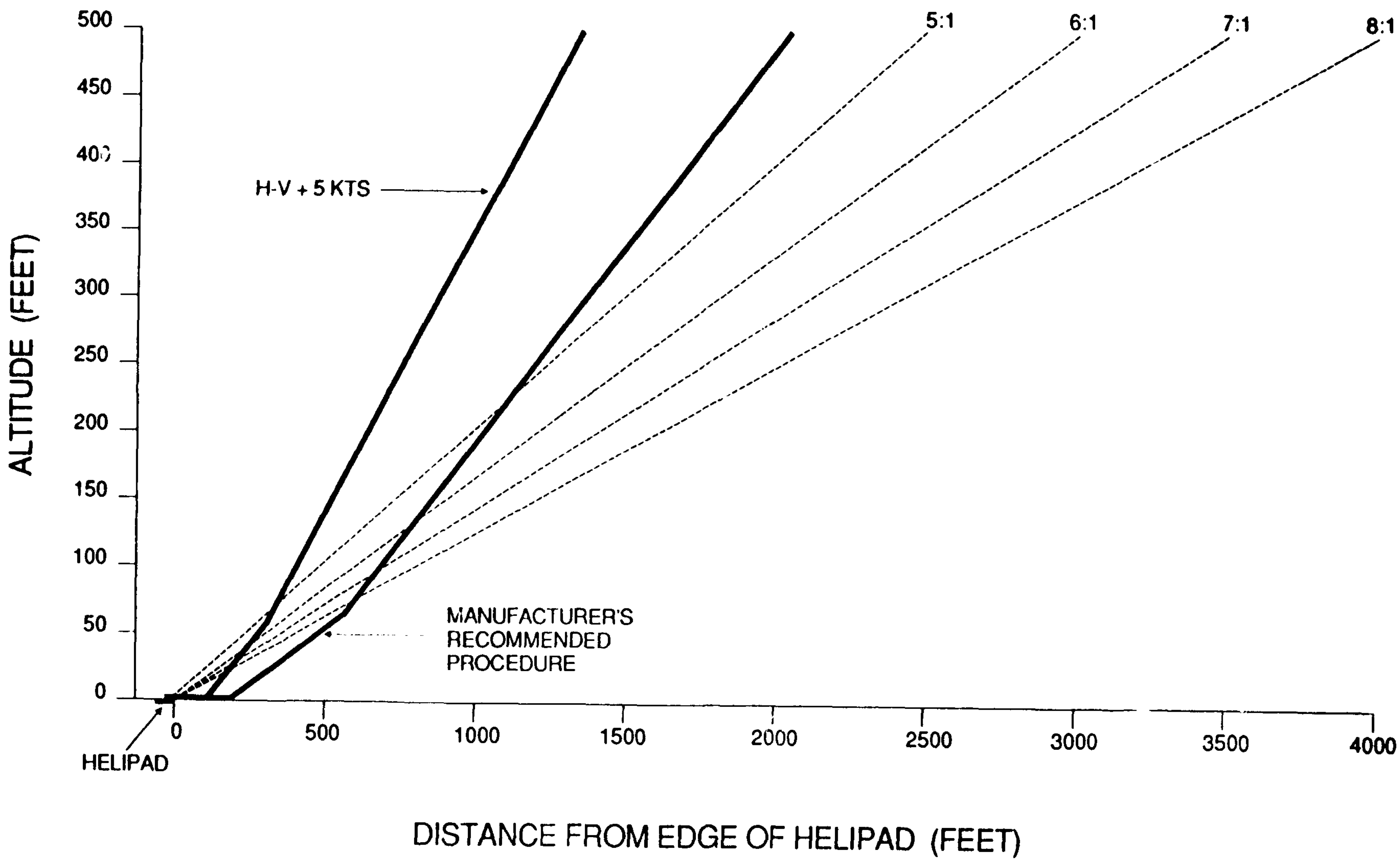
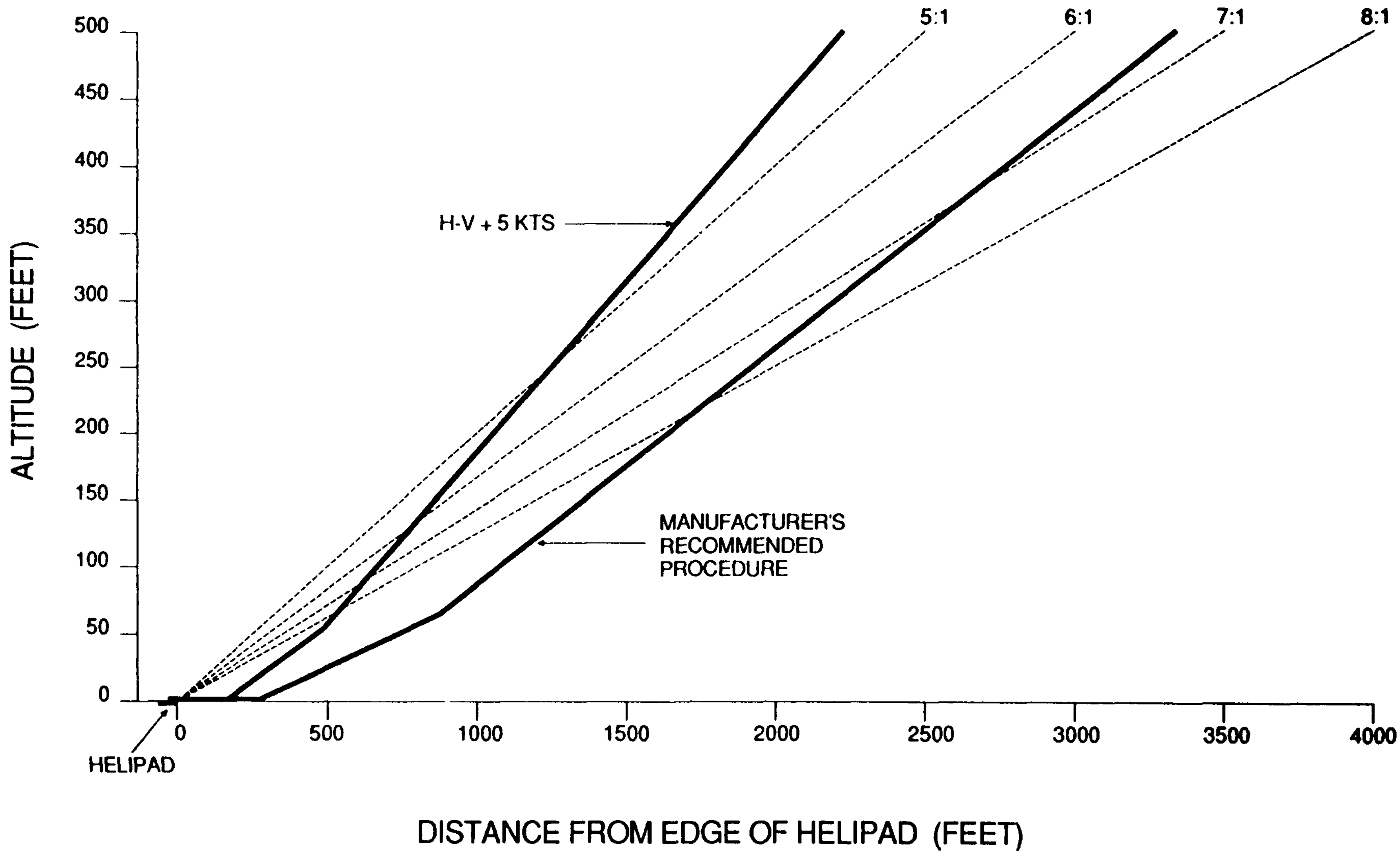
70% MAX. G.W., 4000 FEET, STANDARD DAY



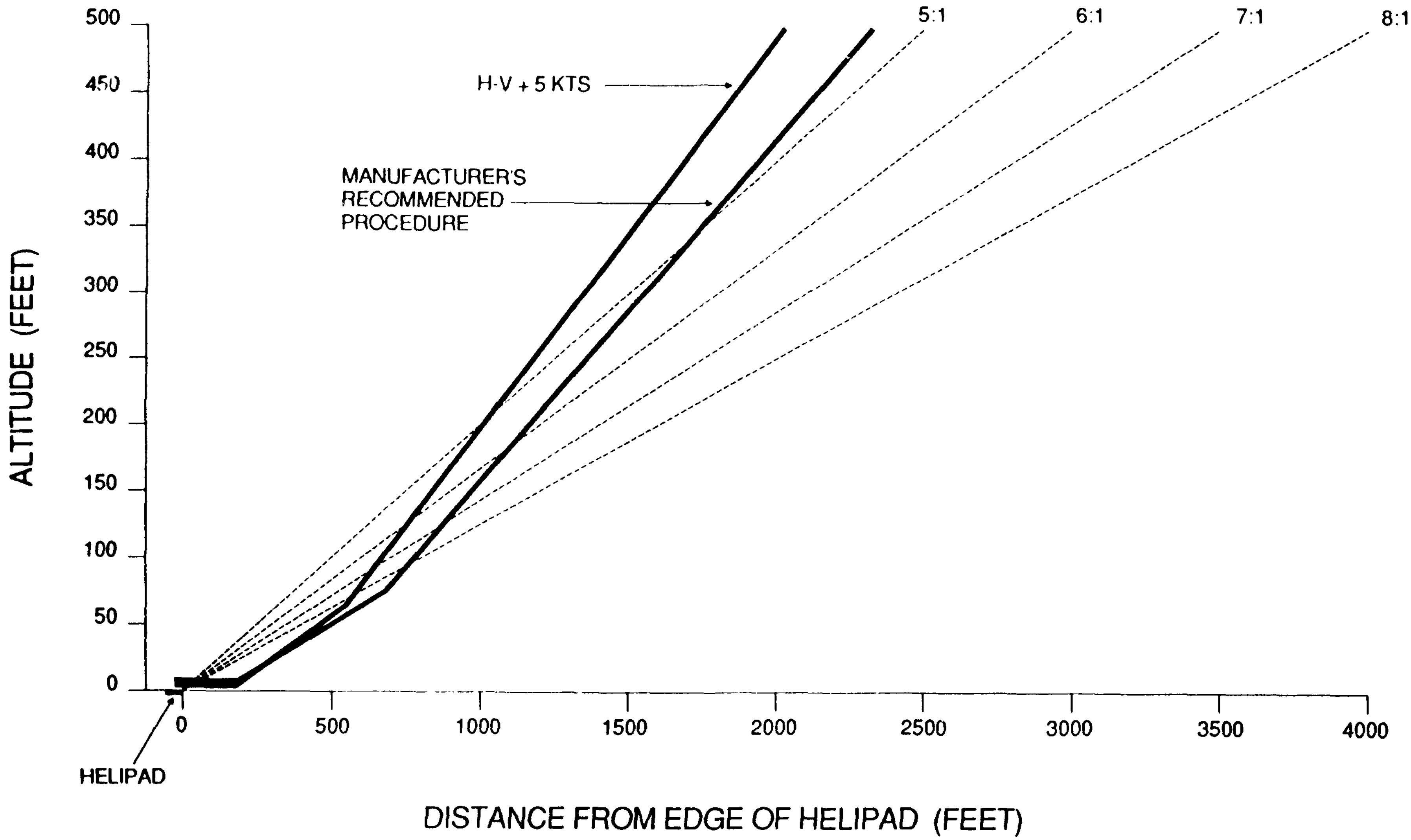
F 28F DEPARTURE PROFILES

70% MAX. G.W., 4000 FEET, HOT DAY



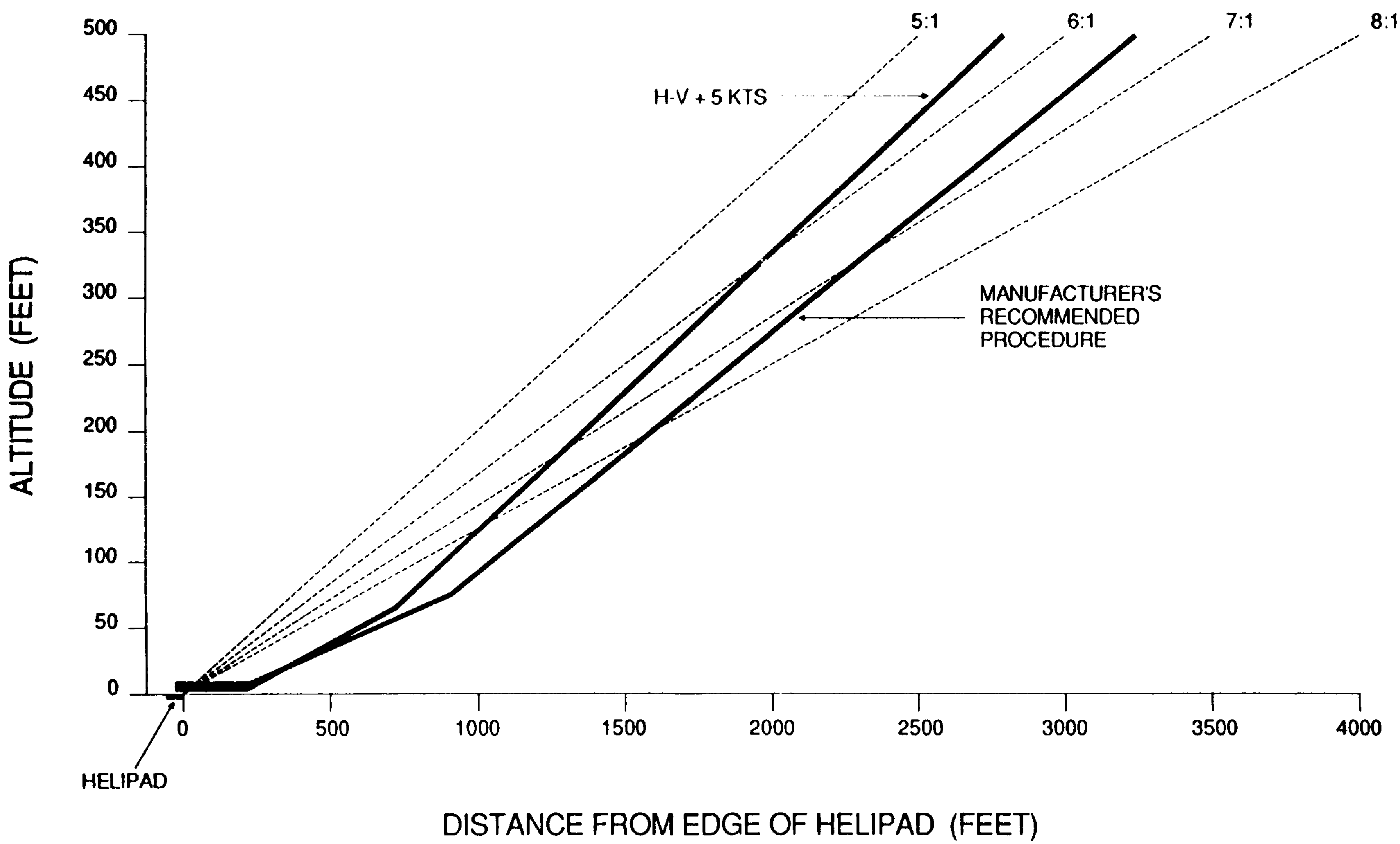
MD 500E DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, STANDARD DAY



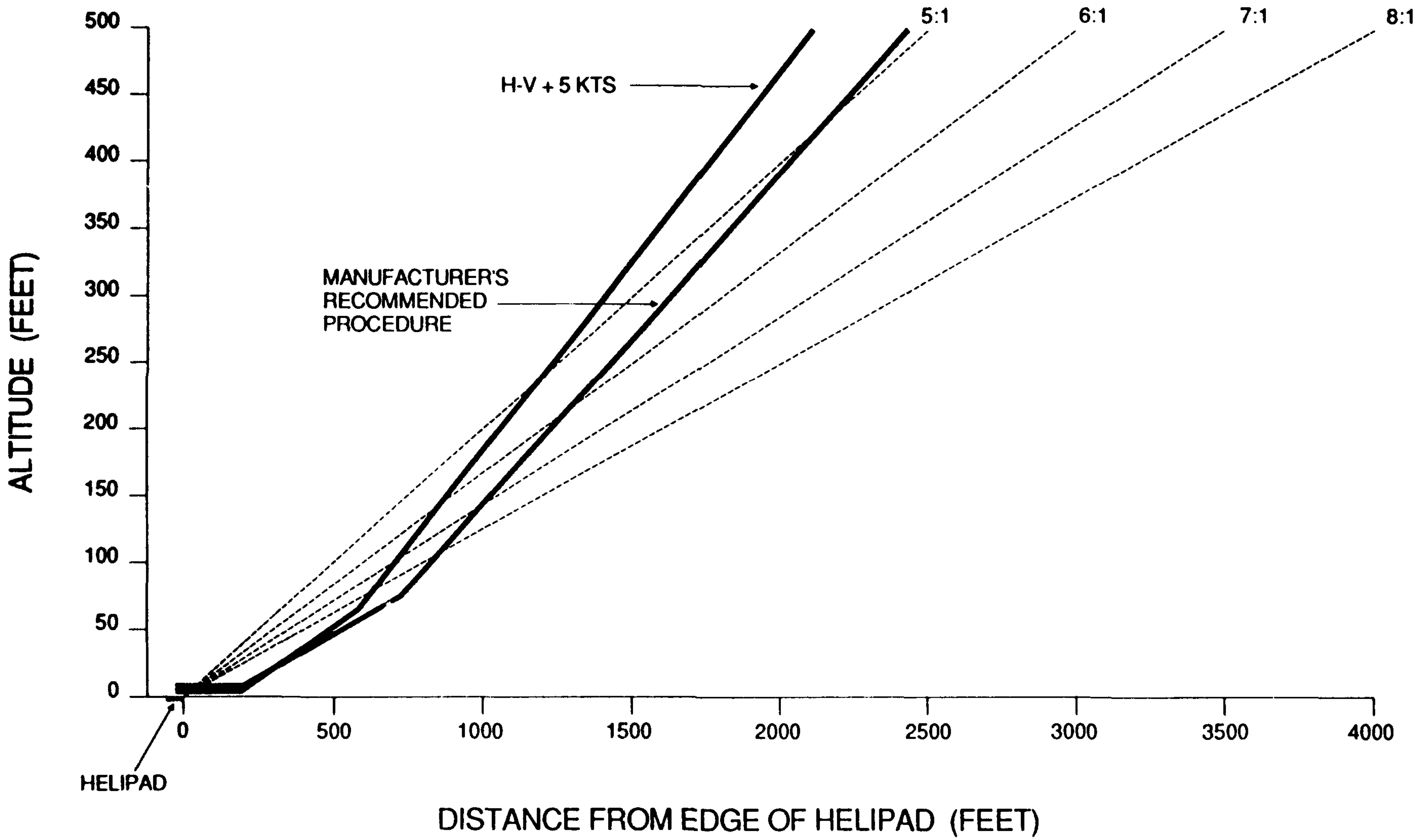
MD 500E DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, HOT DAY



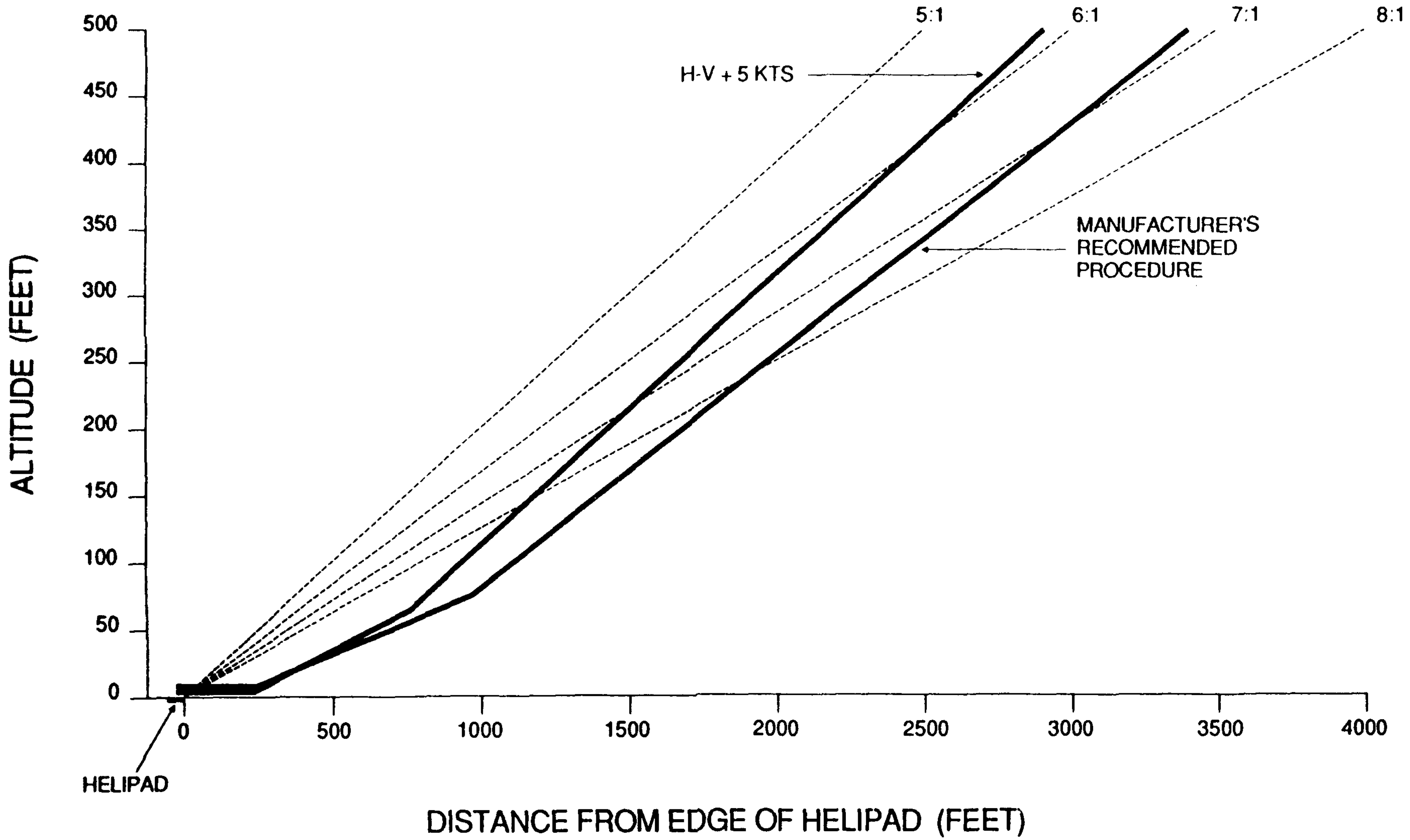
MD 500E DEPARTURE PROFILES

MAX. G.W., 2000 FEET, STANDARD DAY



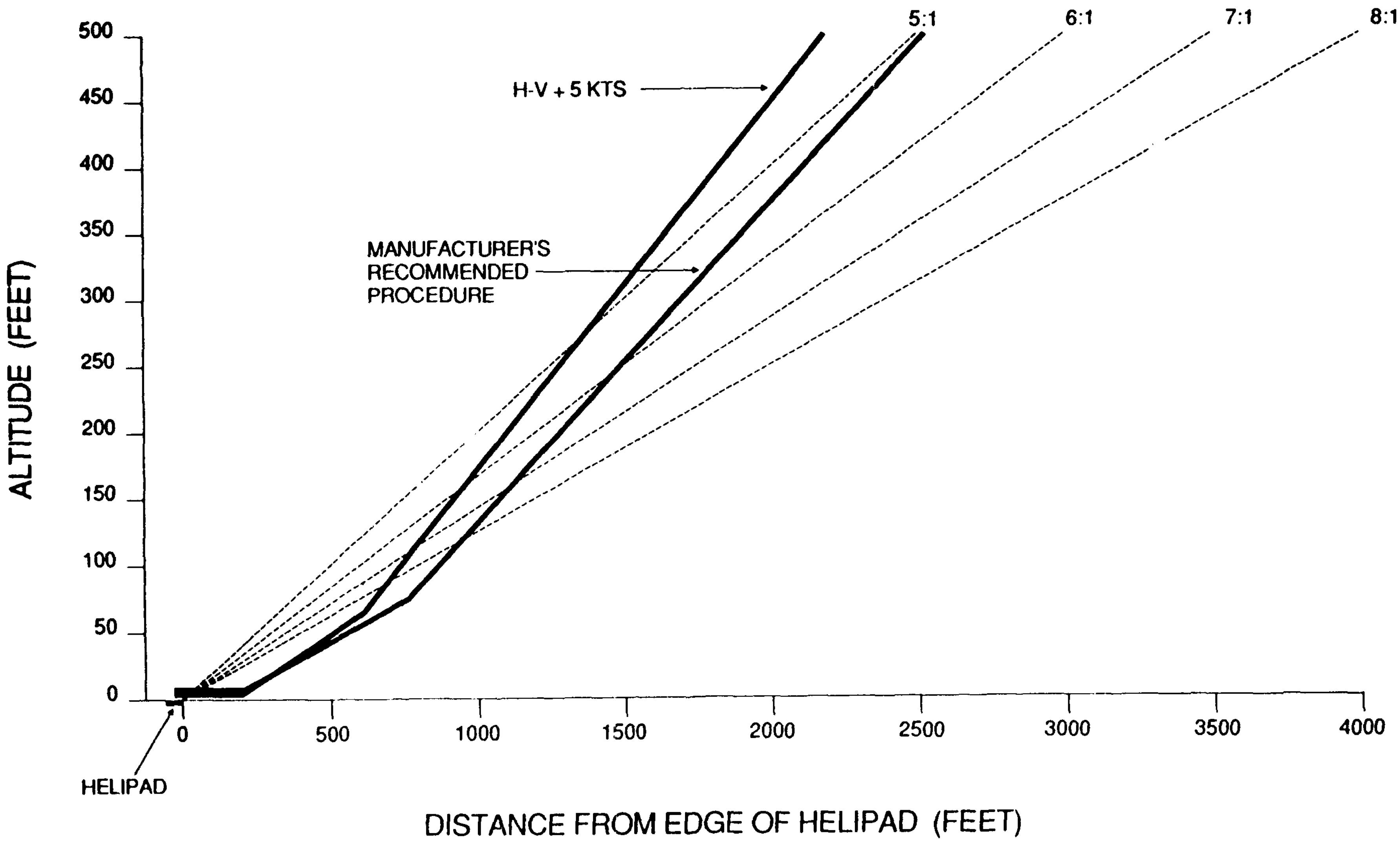
MD 500E DEPARTURE PROFILES

MAX. G.W., 2000 FEET, HOT DAY



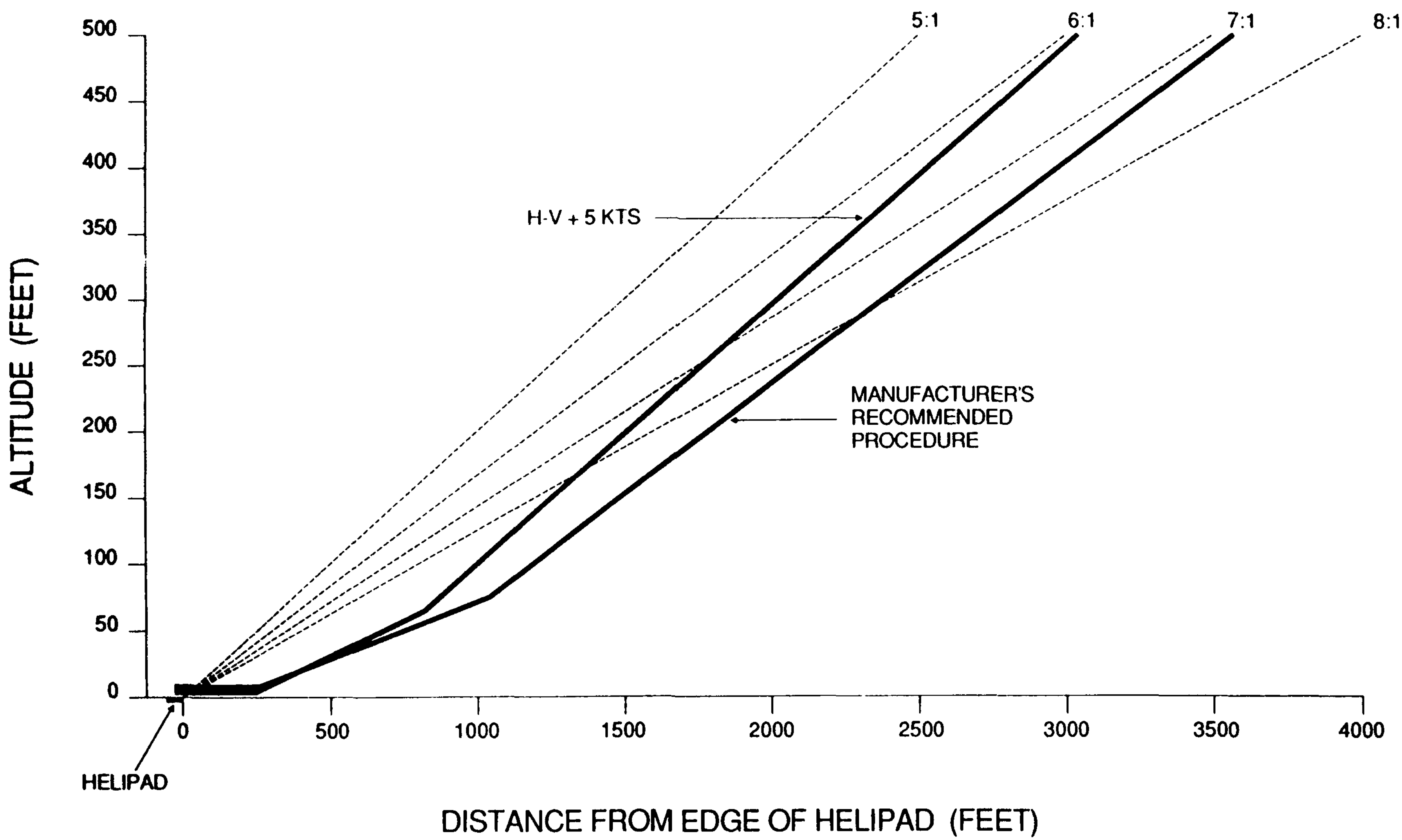
MD 500E DEPARTURE PROFILES

MAX. G.W., 4000 FEET, STANDARD DAY



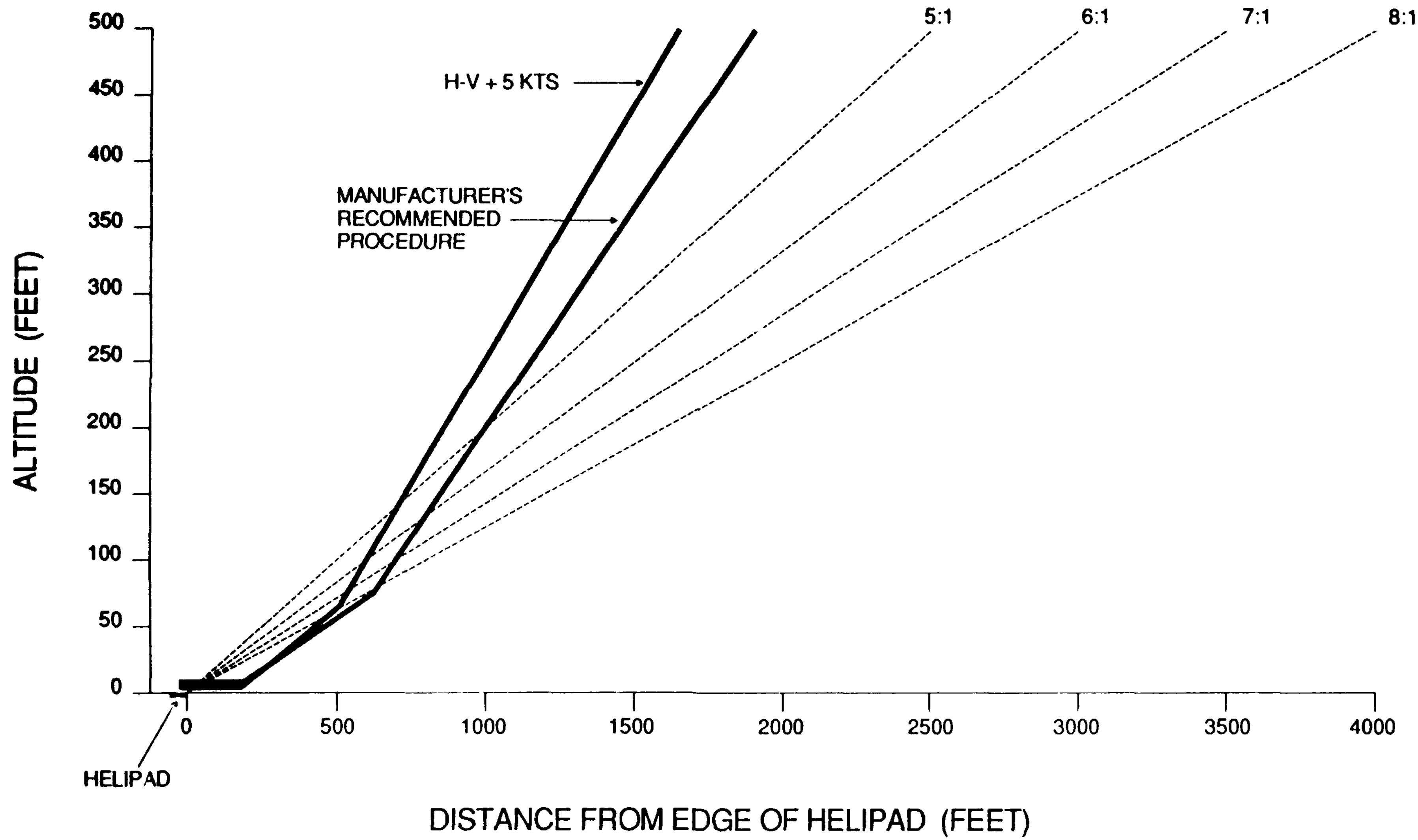
MD 500E DEPARTURE PROFILES

MAX. G.W., 4000 FEET, HOT DAY



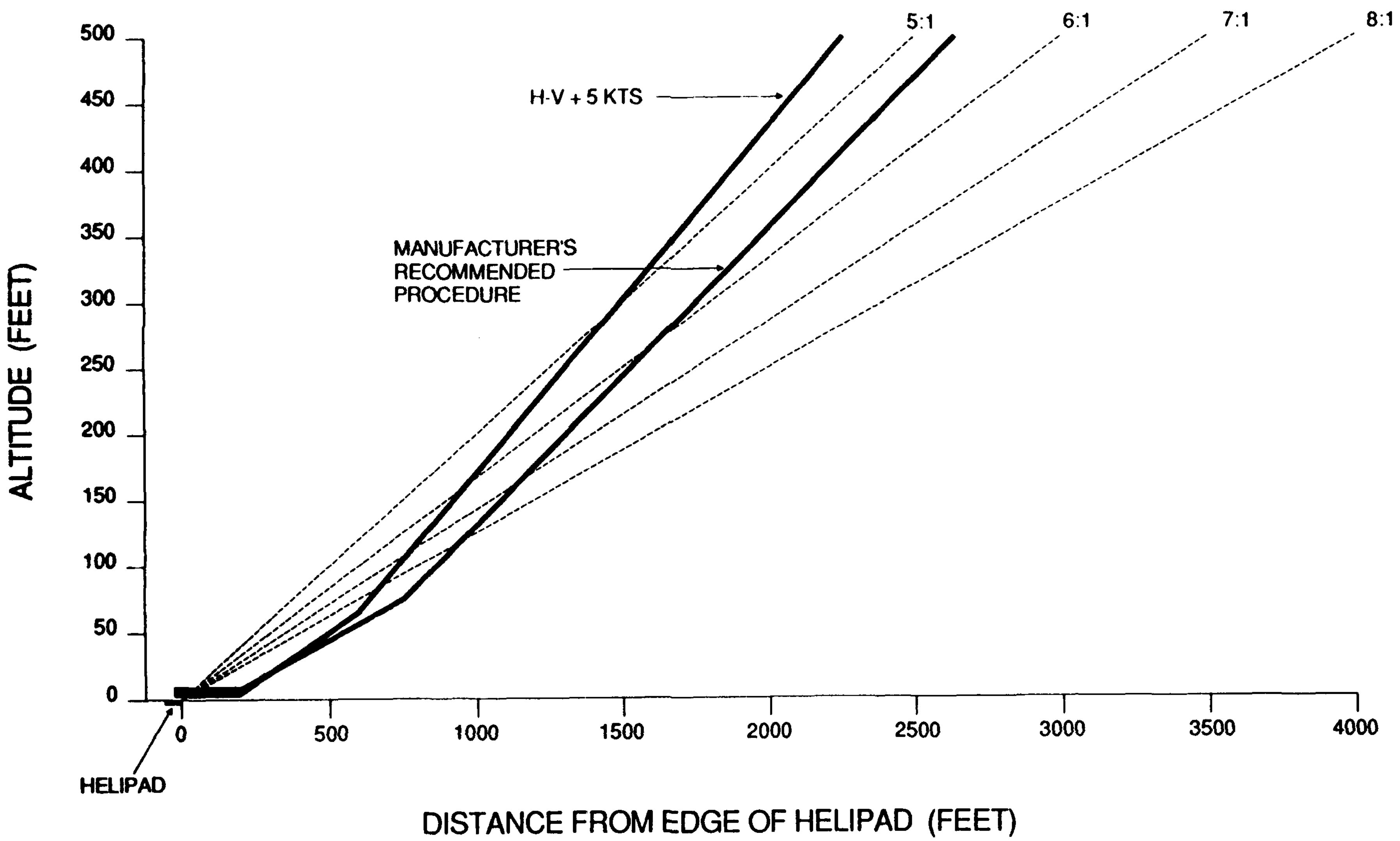
MD 500E DEPARTURE PROFILES

85% MAX. G.W., SEA LEVEL, STANDARD DAY



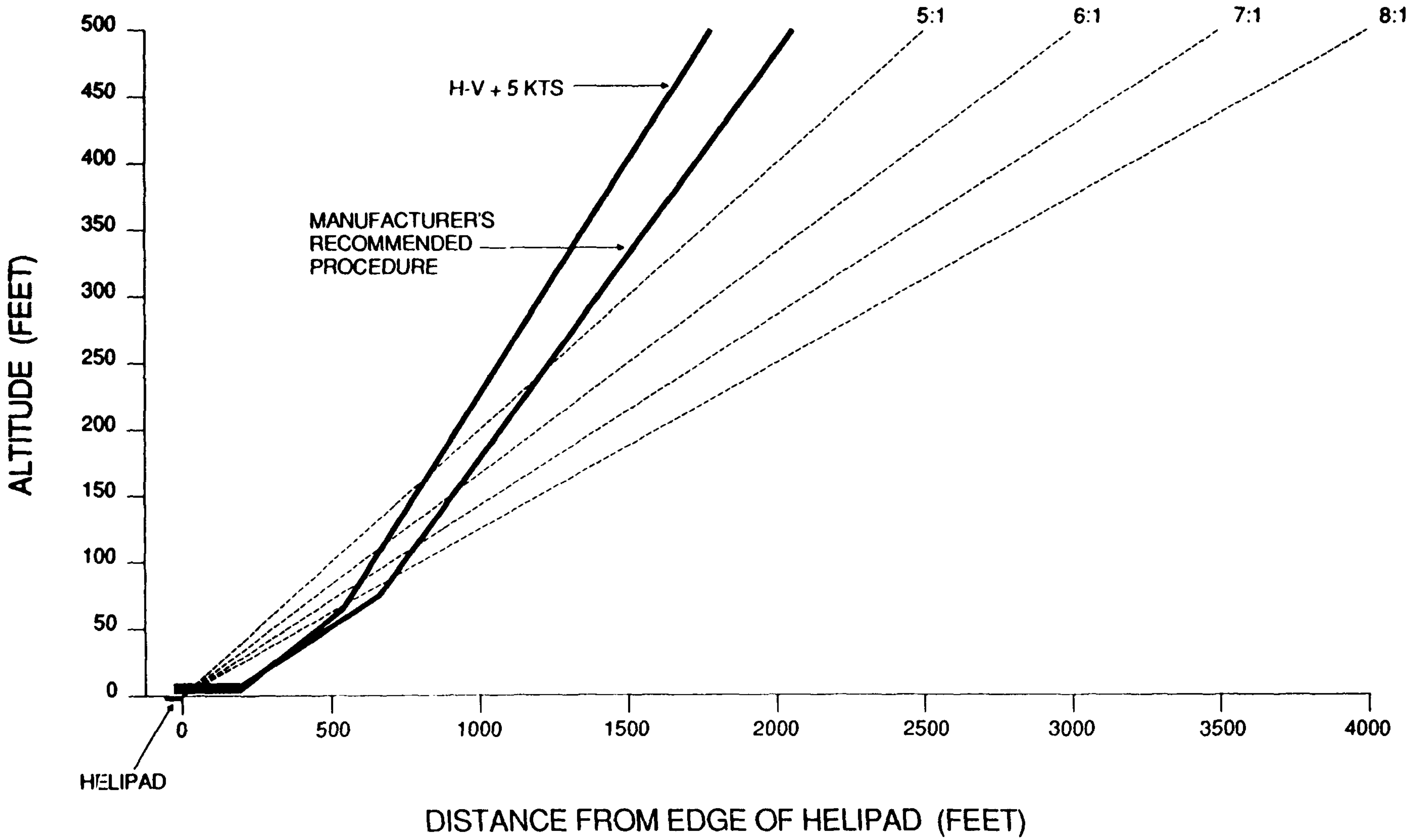
MD 500E DEPARTURE PROFILES

85% MAX. G.W., SEA LEVEL, HOT DAY



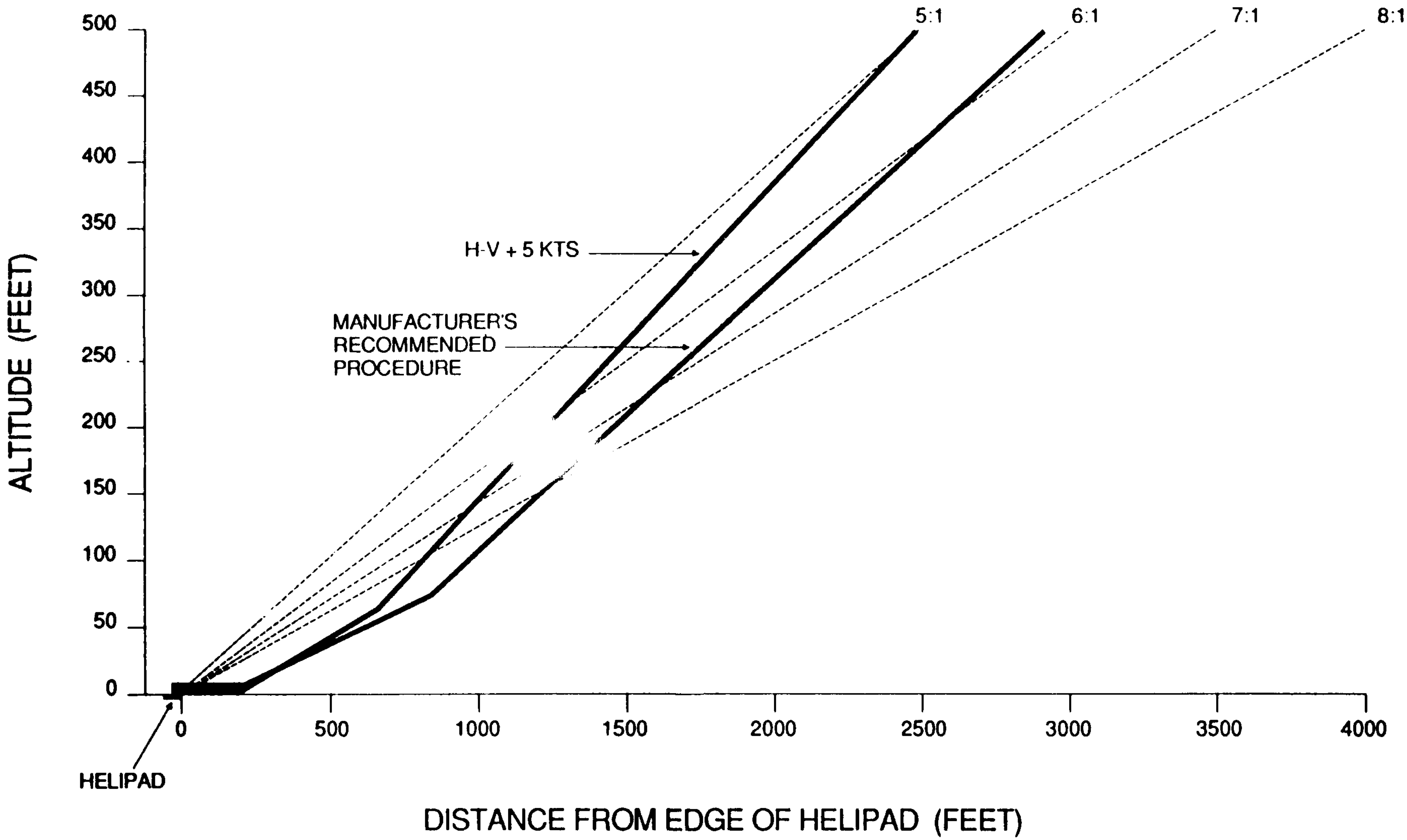
MD 500E DEPARTURE PROFILES

85% MAX. G.W., 2000 FEET, STANDARD DAY



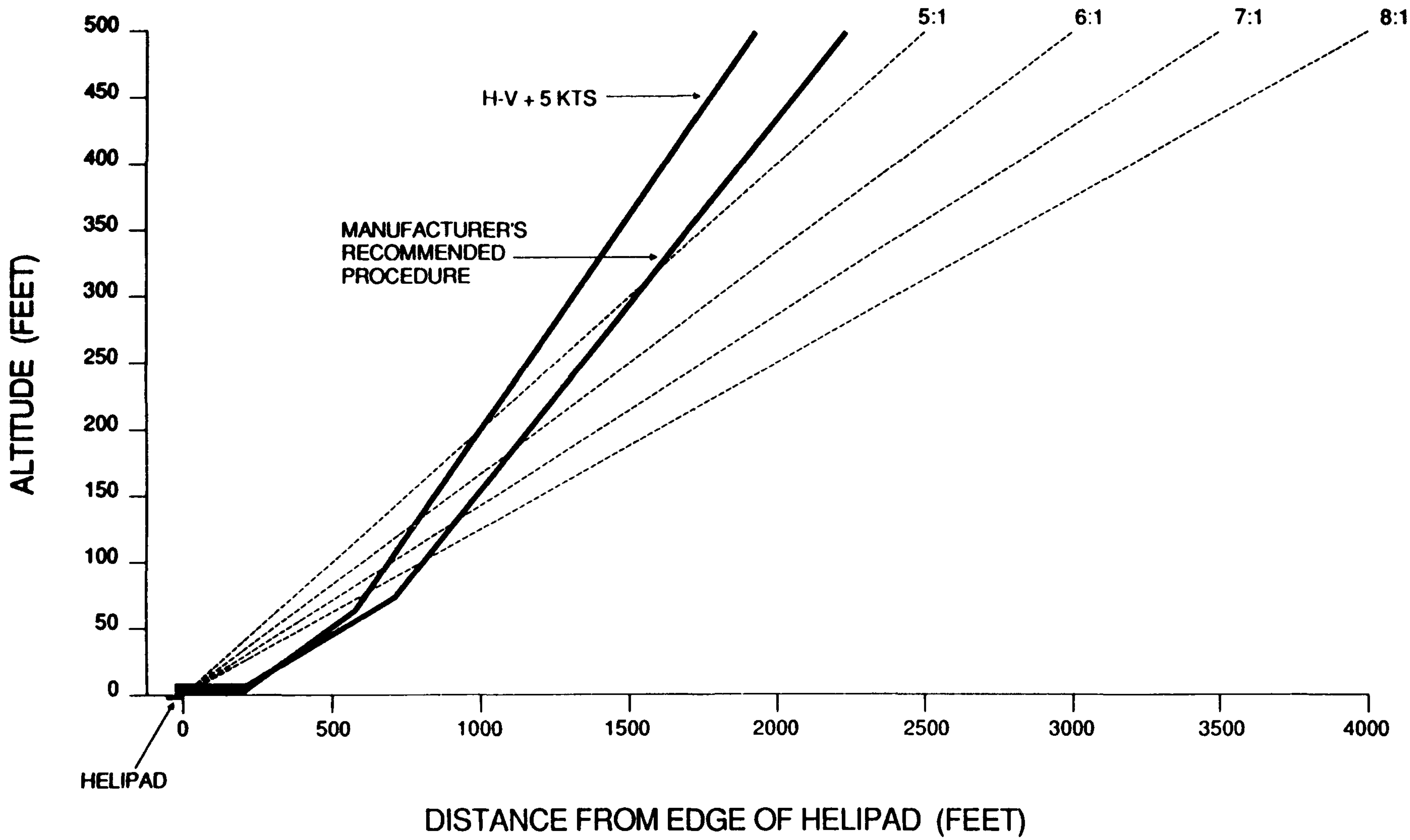
MD 500E DEPARTURE PROFILES

85% MAX. G.W., 2000 FEET, HOT DAY



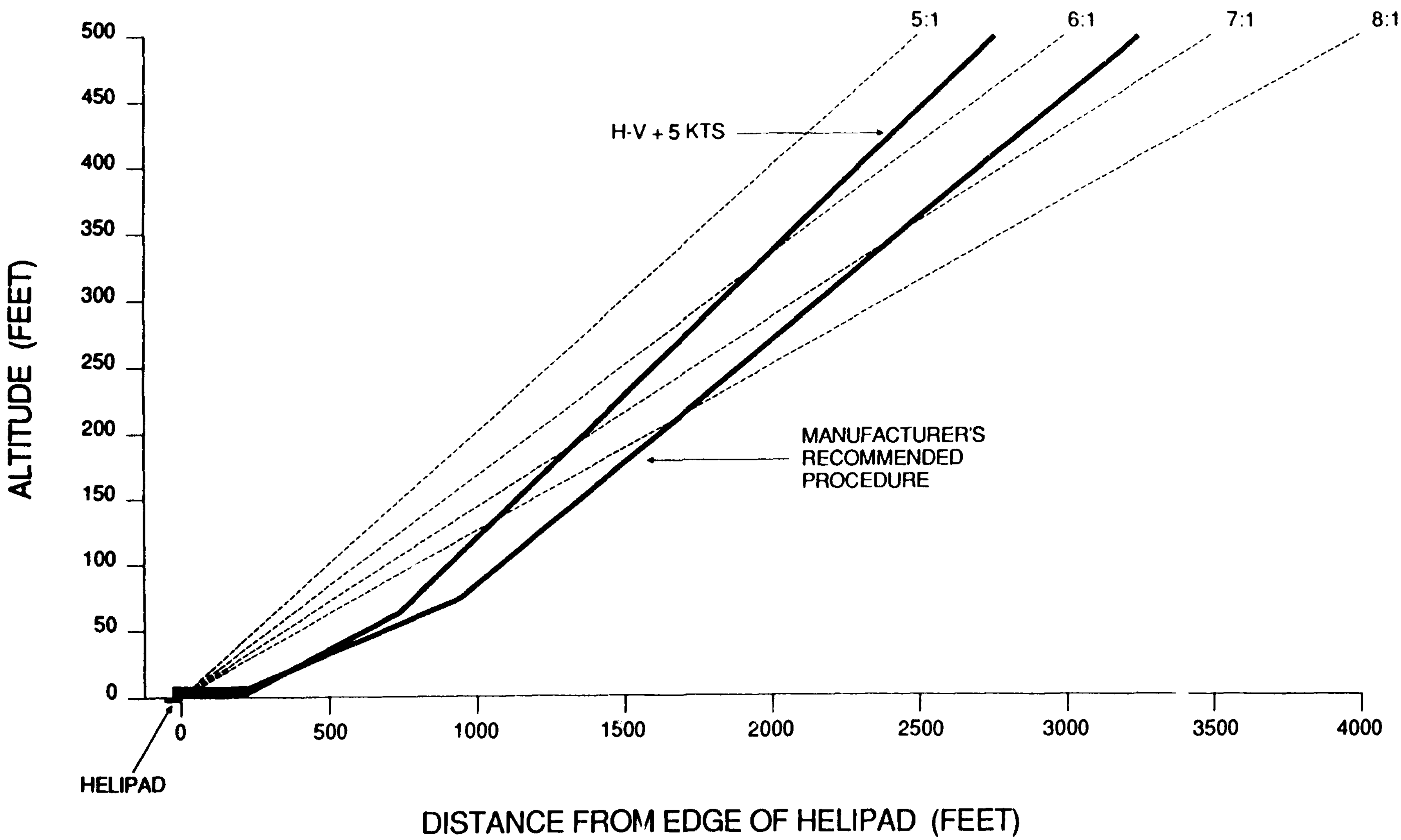
MD 500E DEPARTURE PROFILES

85% MAX. G.W., 4000 FEET, STANDARD DAY



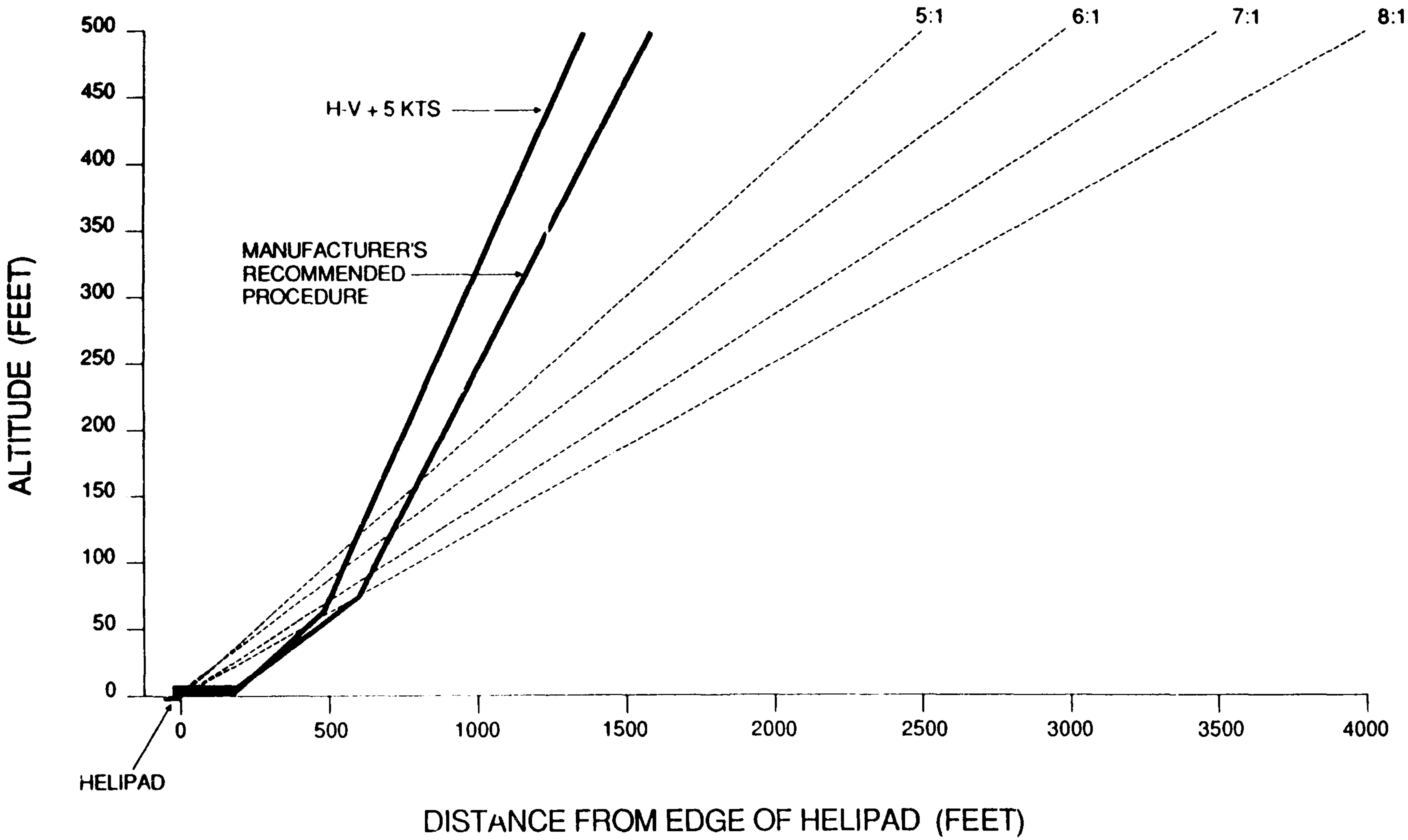
MD 500E DEPARTURE PROFILES

85% MAX. G.W., 4000 FEET, HOT DAY



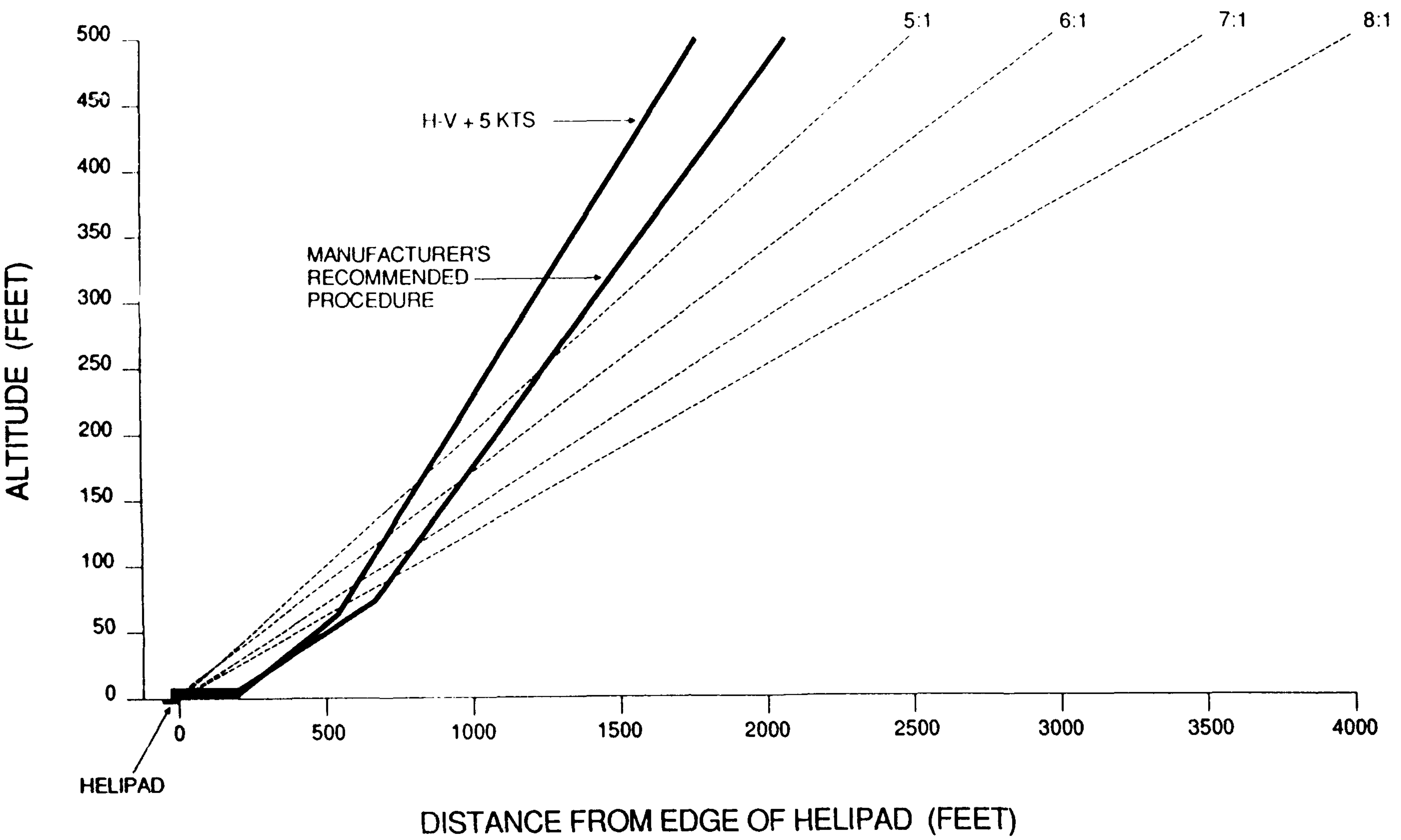
MD 500E DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL, STANDARD DAY



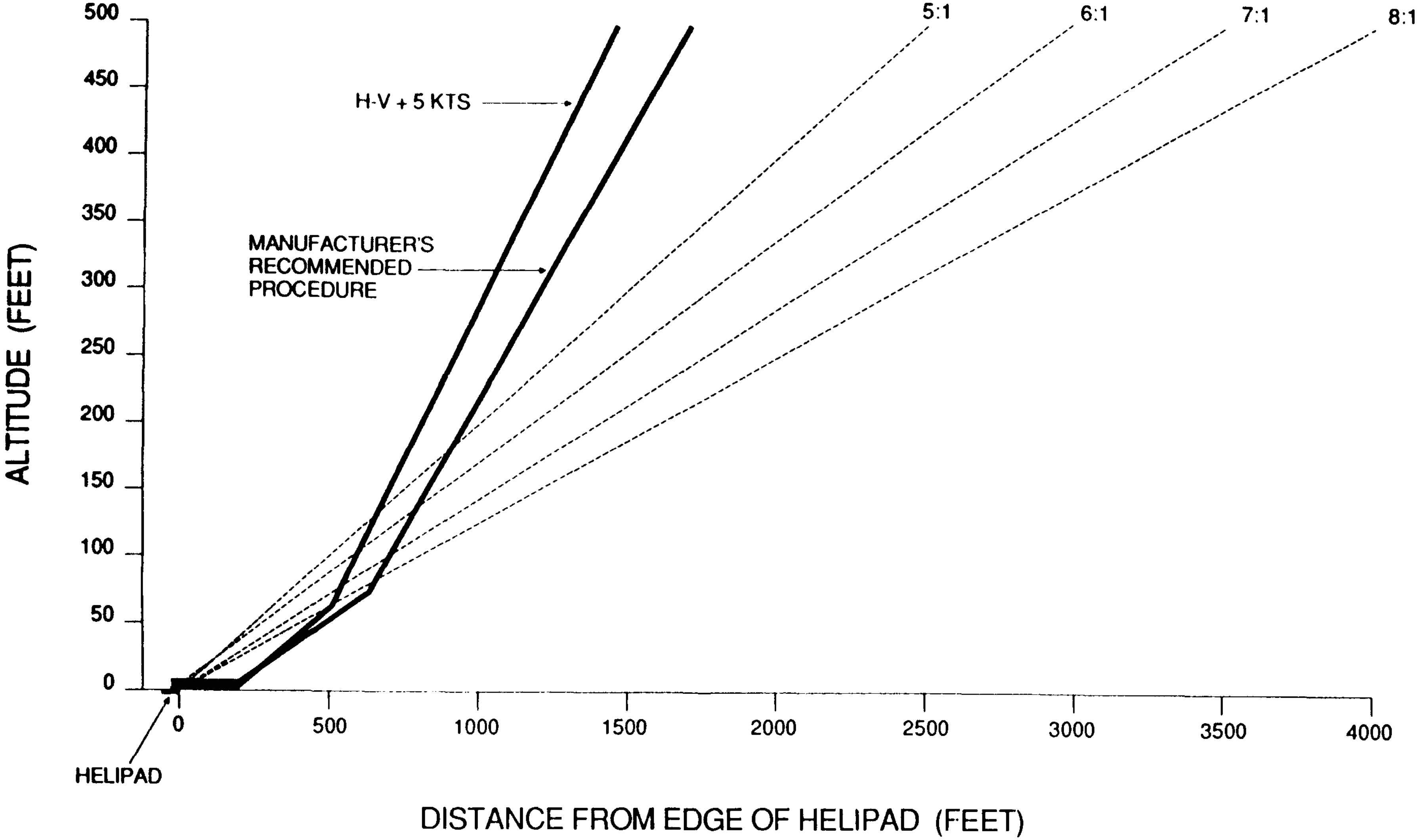
MD 500E DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL, HOT DAY



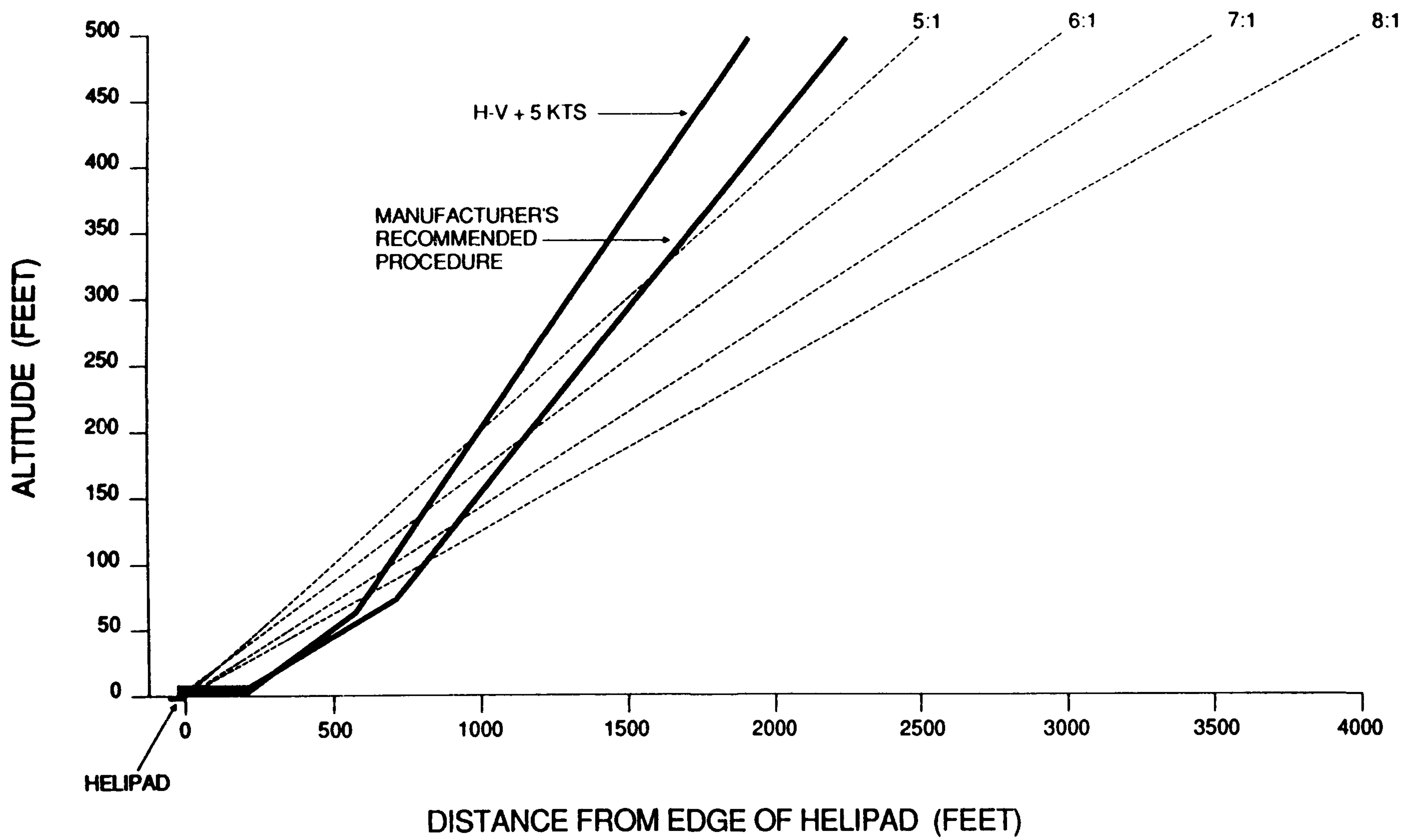
MD 500E DEPARTURE PROFILES

70% MAX. G.W., 2000 FEET, STANDARD DAY



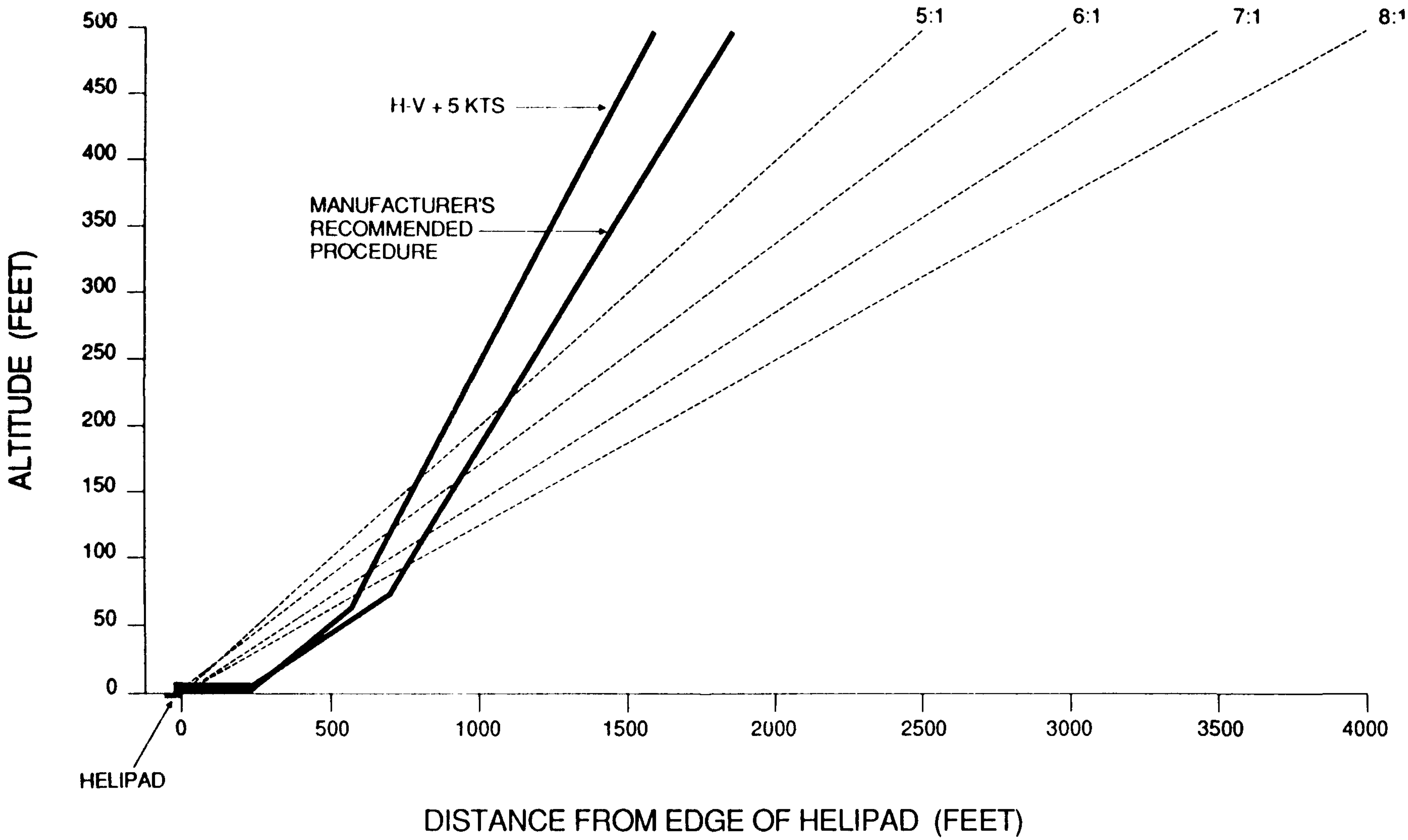
MD 500E DEPARTURE PROFILES

70% MAX. G.W., 2000 FEET, HOT DAY



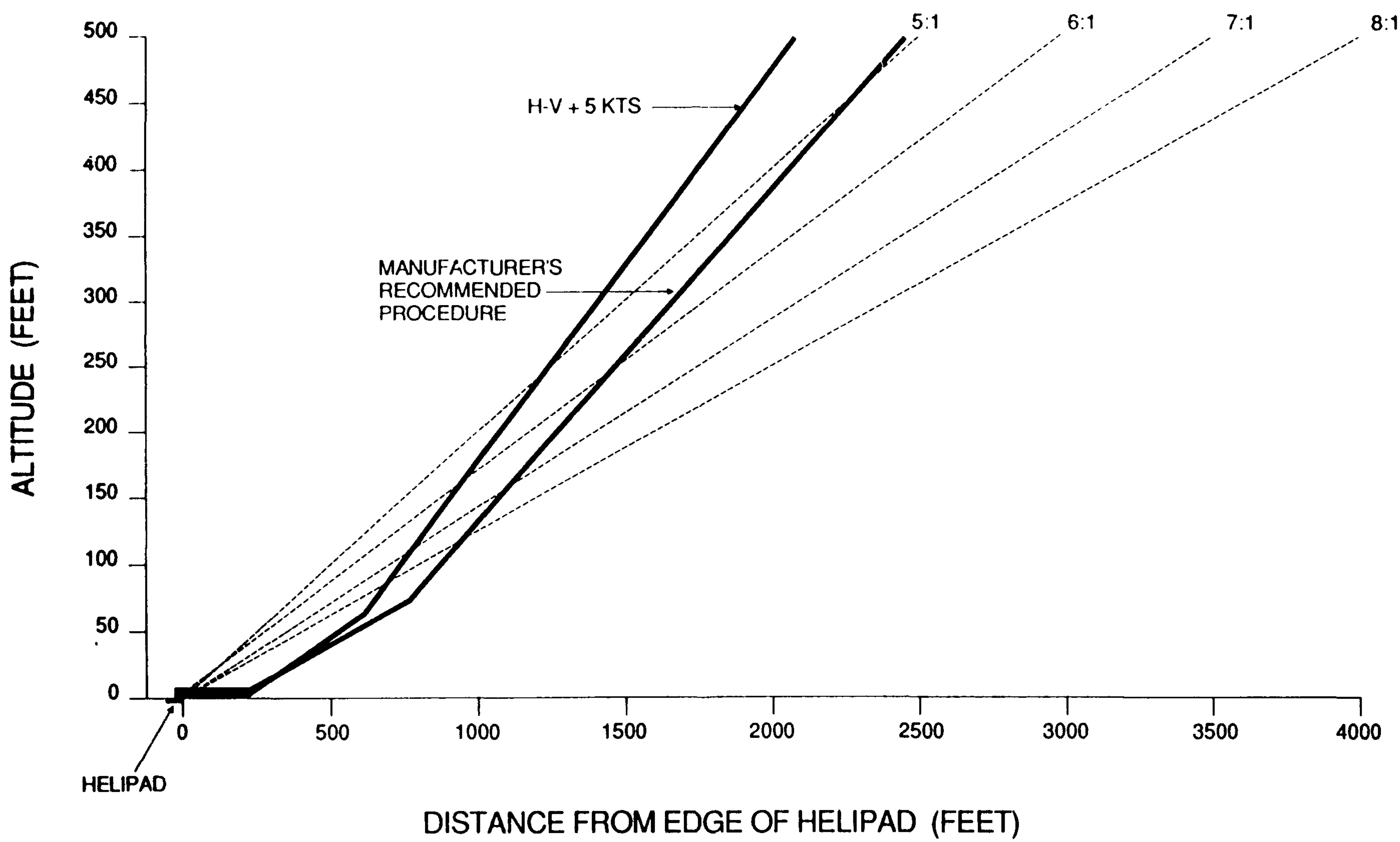
MD 500E DEPARTURE PROFILES

70% MAX. G.W., 4000 FEET, STANDARD DAY



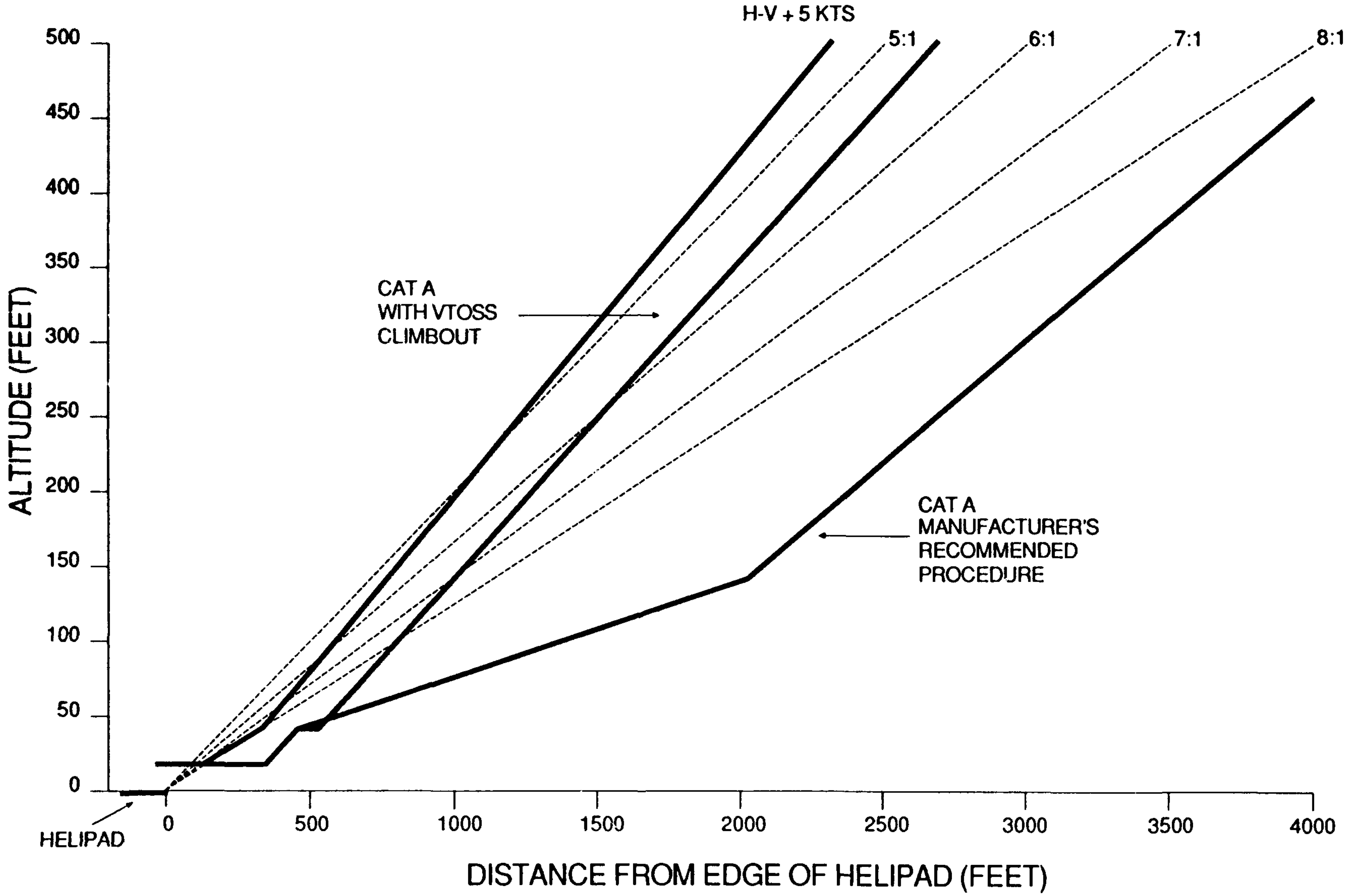
MD 500E DEPARTURE PROFILES

70% MAX. G.W., 4000 FEET, HOT DAY



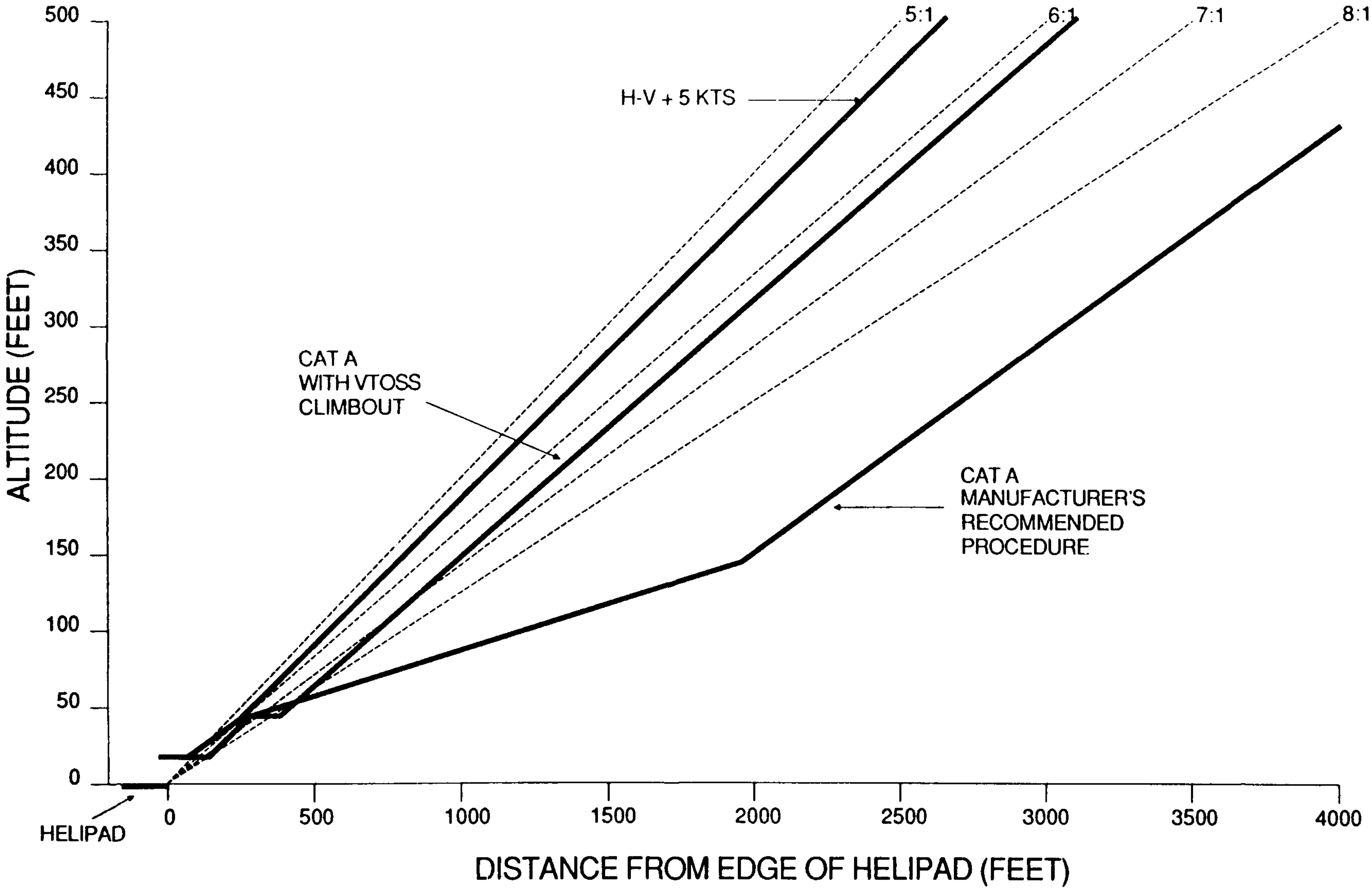
BV 234 LR DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, STANDARD DAY



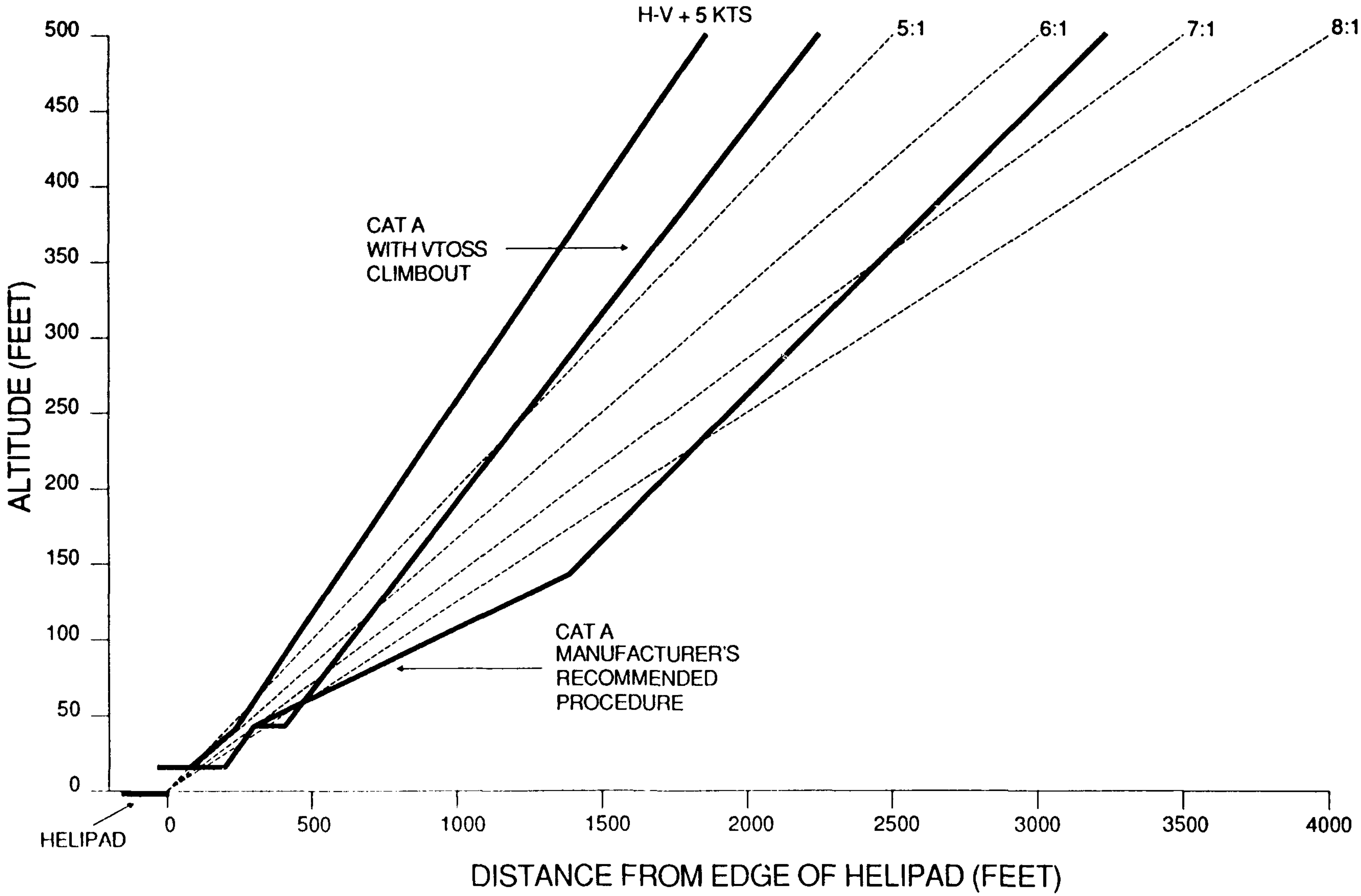
BV 234 LR DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, HOT DAY



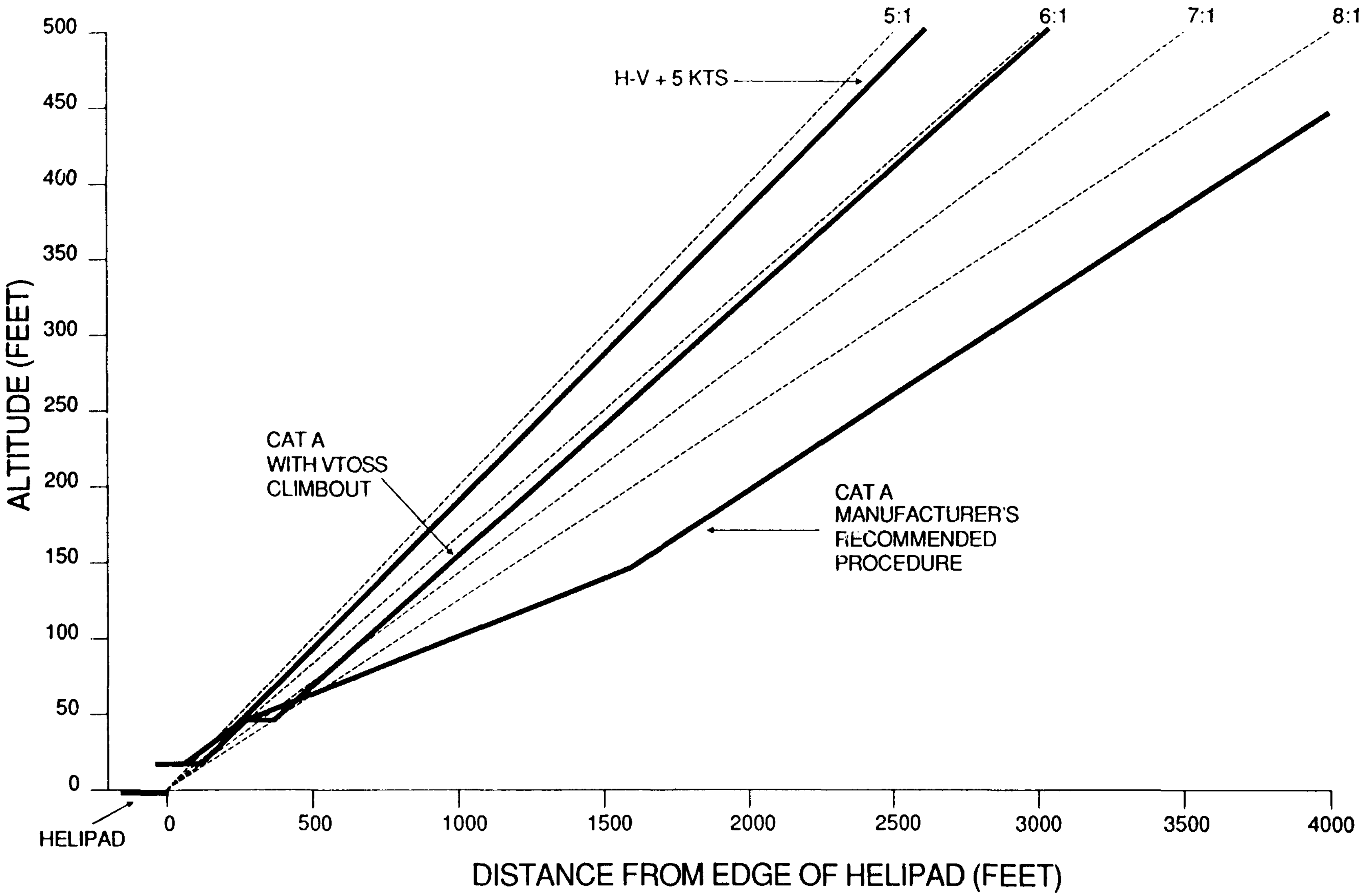
BV 234 LR DEPARTURE PROFILES

MAX. G.W., 2000 FEET, STANDARD DAY



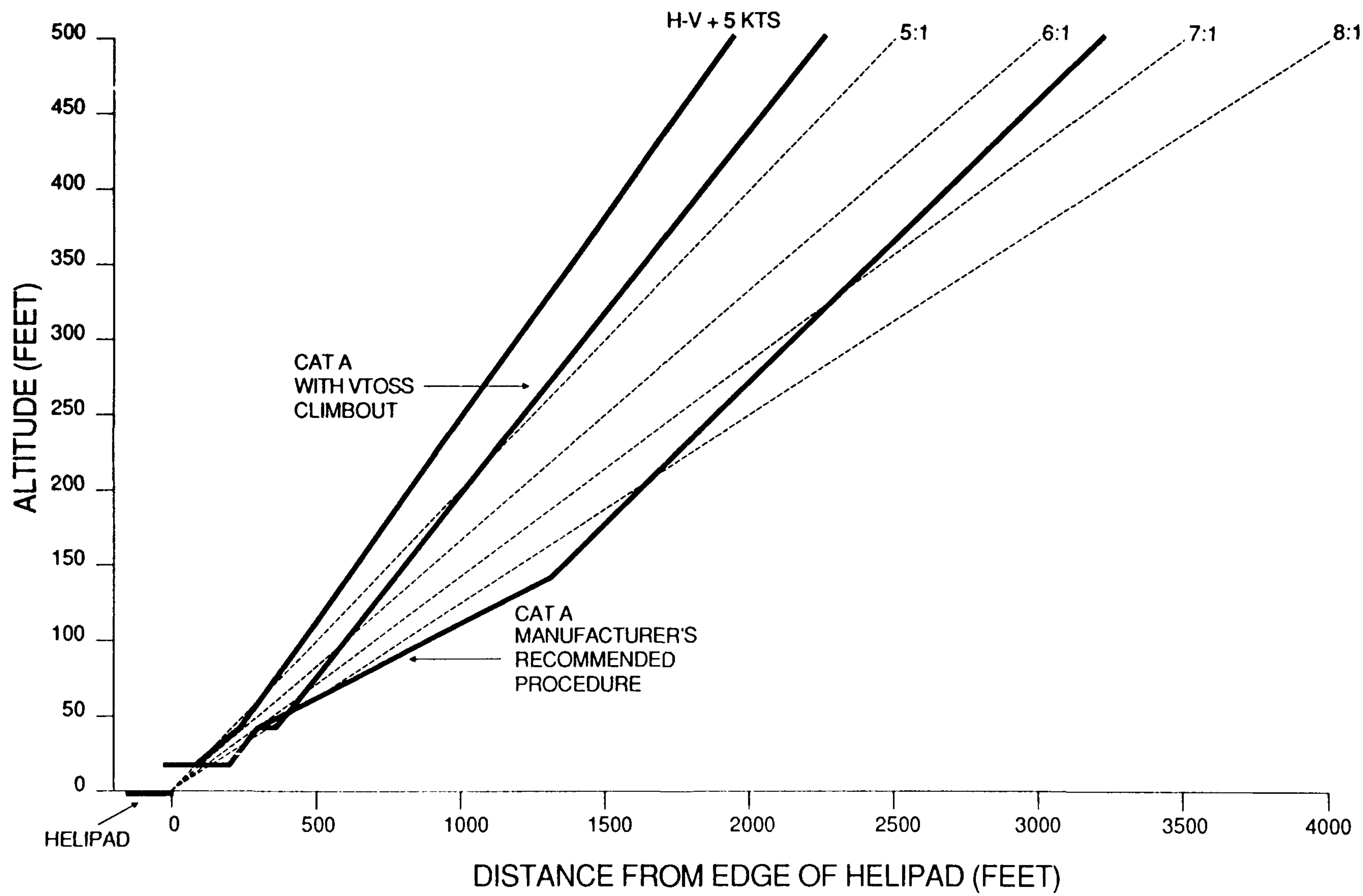
BV 234 LR DEPARTURE PROFILES

MAX. G.W., 2000 FEET, HOT DAY



BV 234 LR DEPARTURE PROFILES

MAX. G.W., 4000 FEET, STANDARD DAY

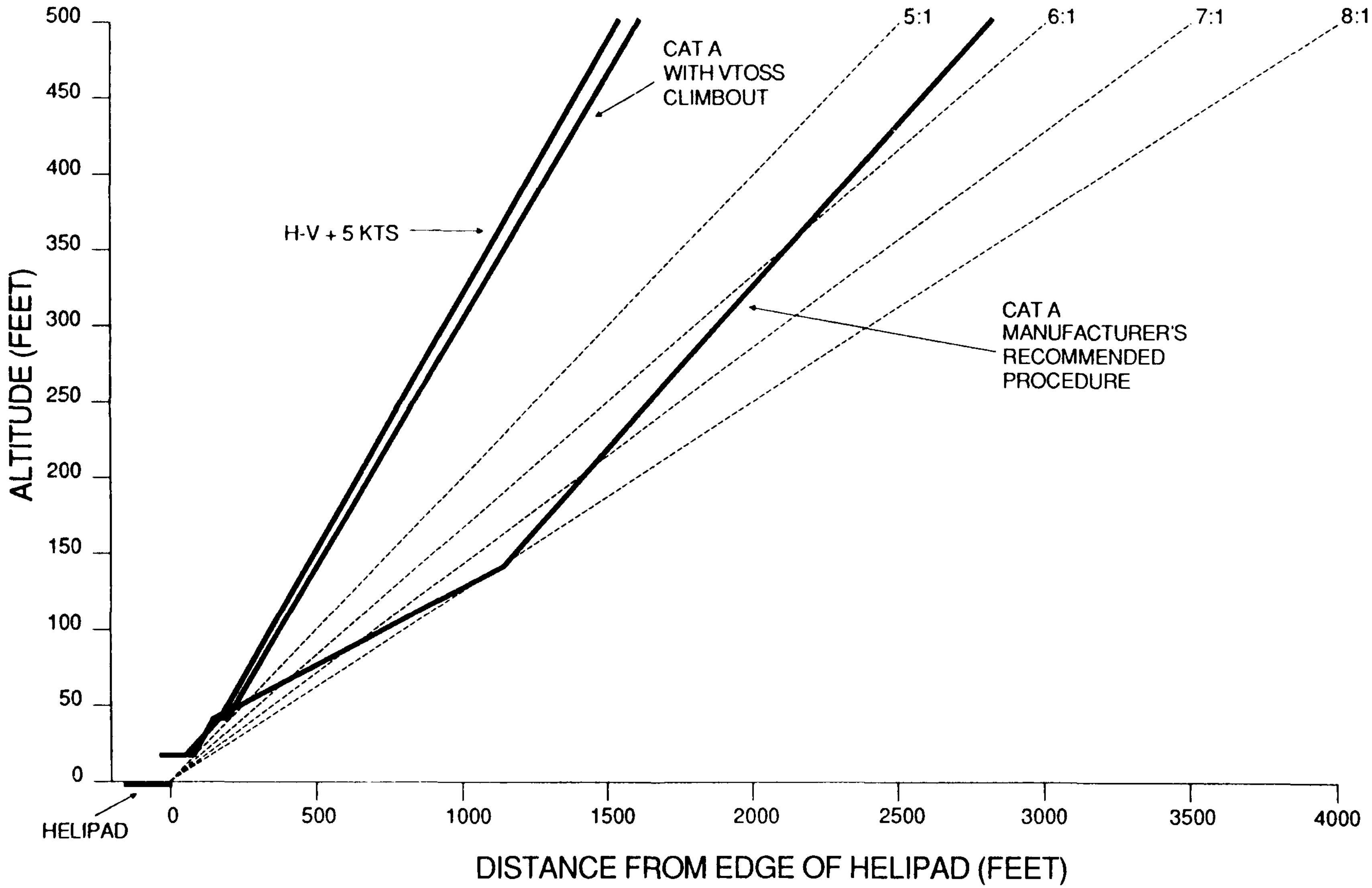


MAXIMUM G.W., 4000 FEET, HOT DAY

The maximum allowable takeoff weight is below the 85% max gross weight limit and therefore a profile was not created at this weight.

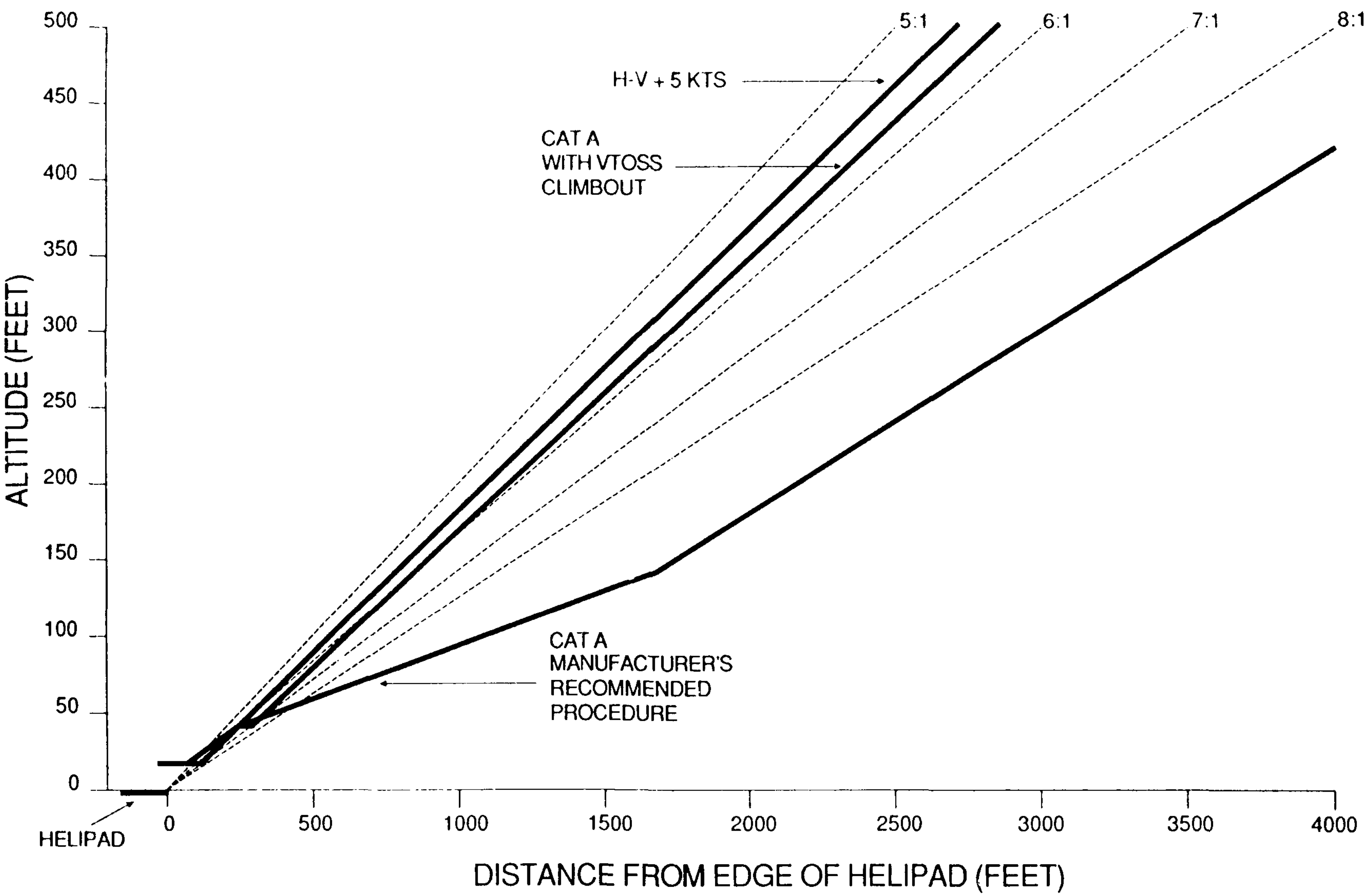
BV 234 LR DEPARTURE PROFILES

85% MAX G.W., SEA LEVEL, STANDARD DAY



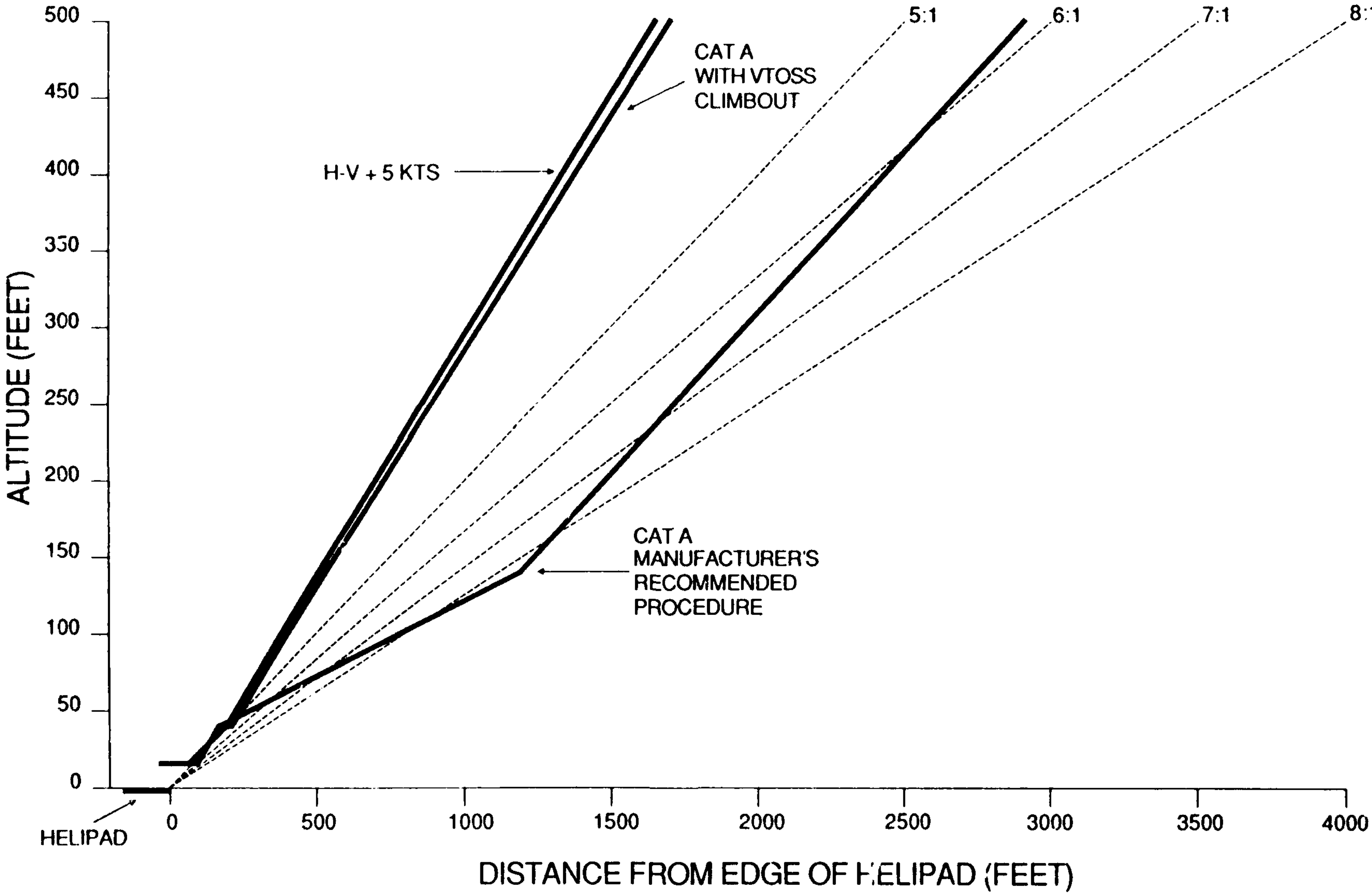
BV 234 LR DEPARTURE PROFILES

85% MAX. G.W., SEA LEVEL, HOT DAY



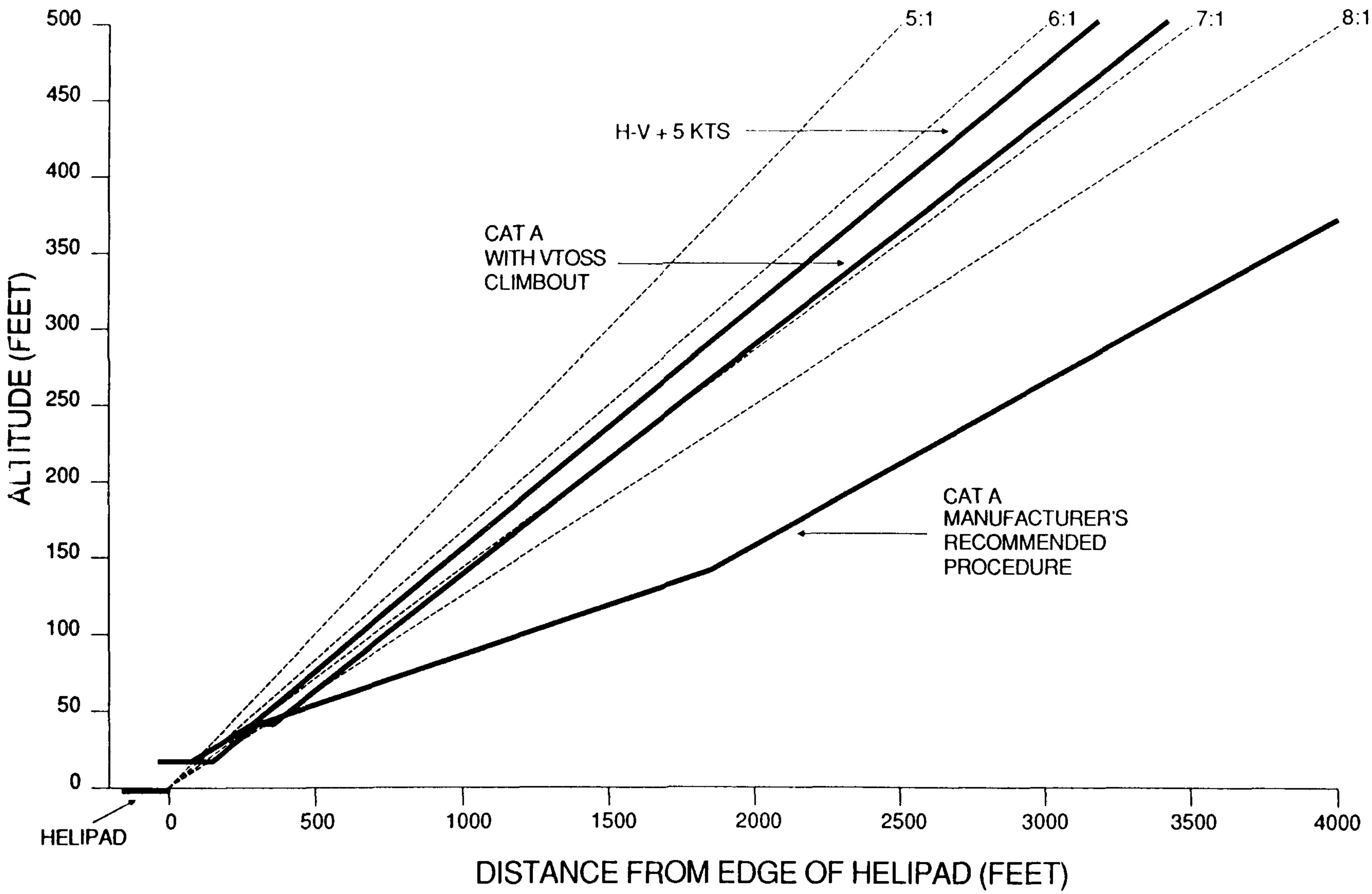
BV 234 LR DEPARTURE PROFILES

85% MAX G.W., 2000 FEET, STANDARD DAY



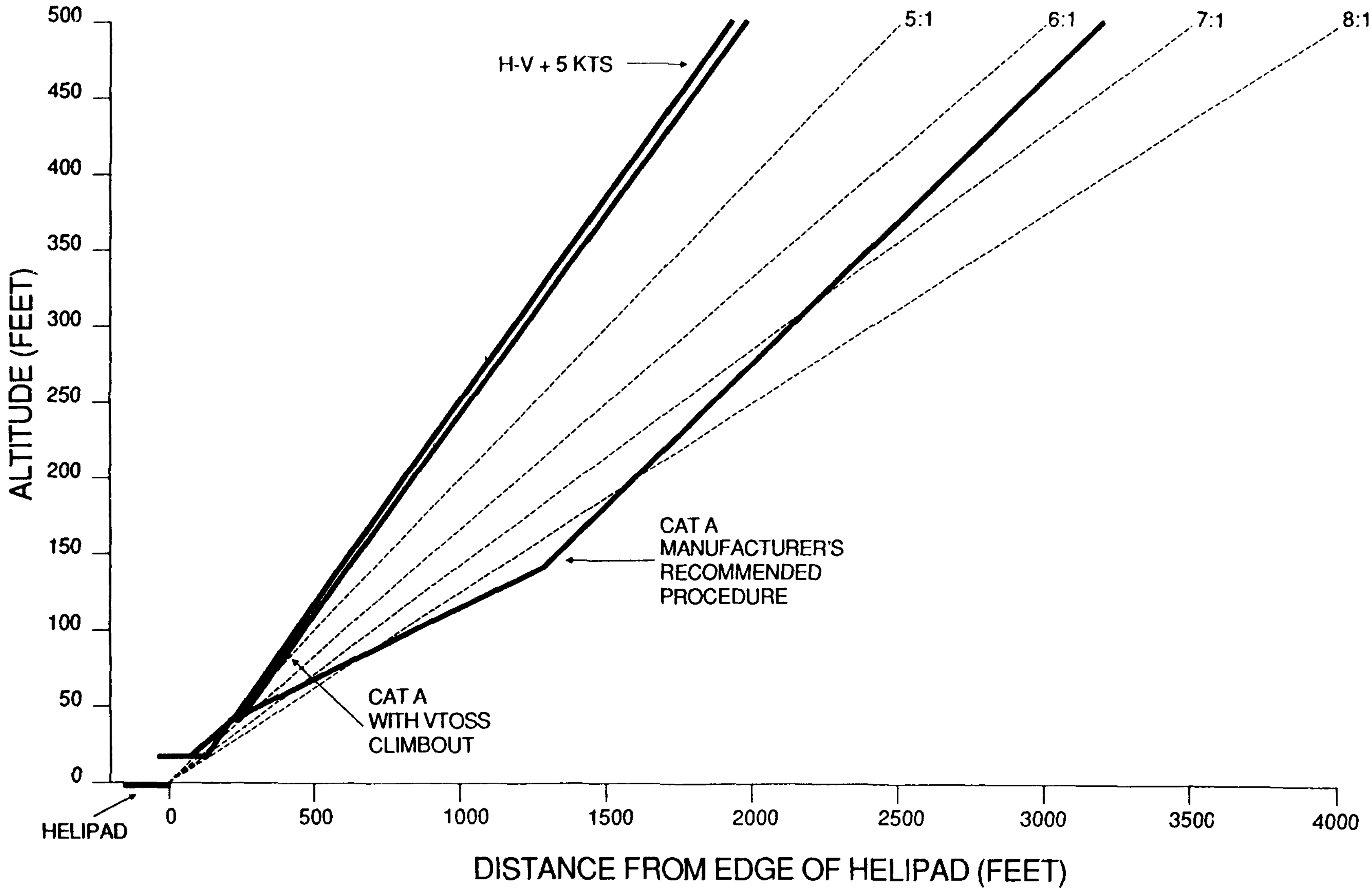
BV 234 LR DEPARTURE PROFILES

85% MAX G.W., 2000 FEET, HOT DAY



BV 234 LR DEPARTURE PROFILES

85% MAX G.W., 4000 FEET, STANDARD DAY

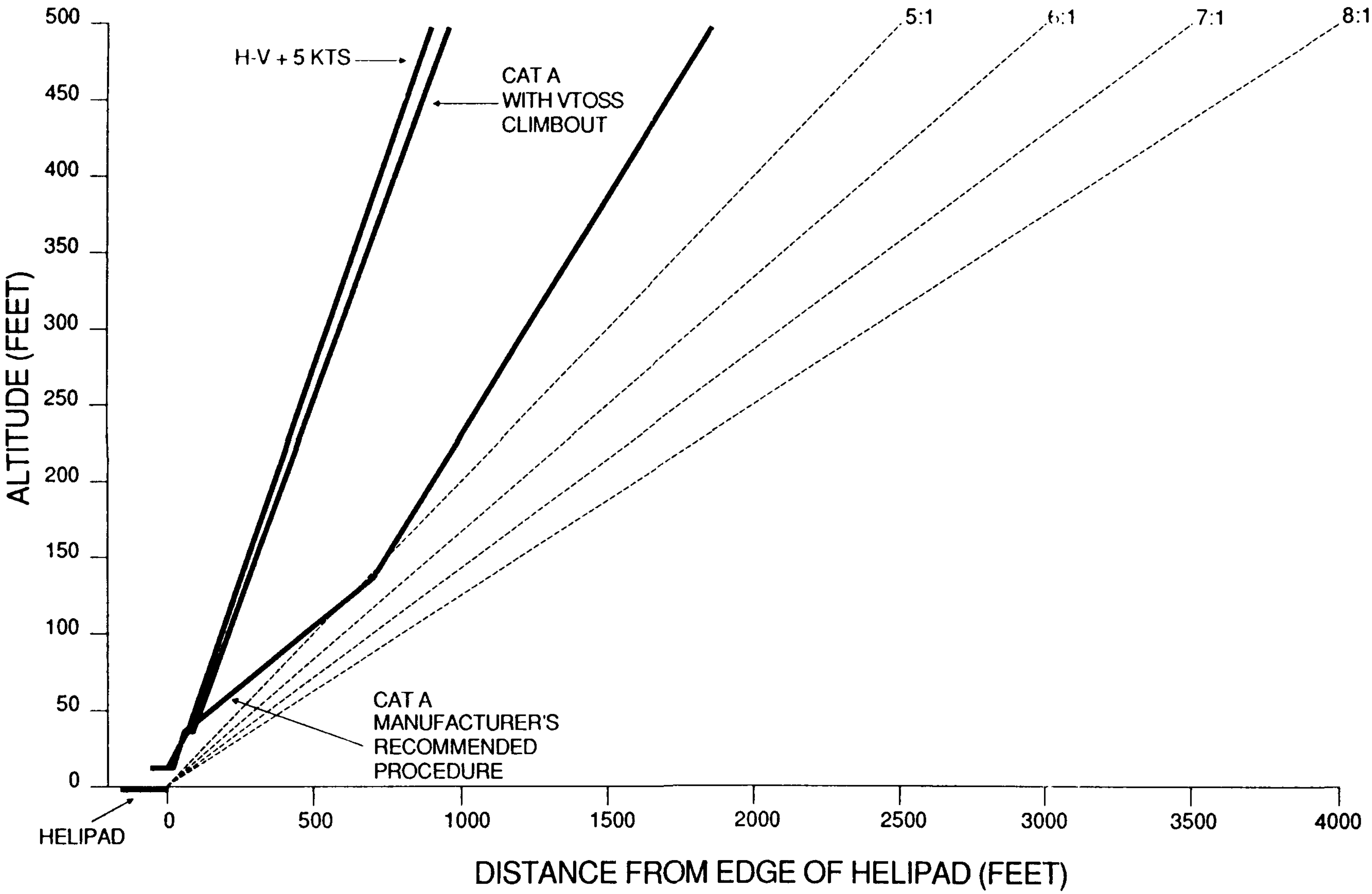


85% MAX G.W., 4000 FEET, HOT DAY

This weight exceeds the maximum allowable takeoff weight for the BV 234 LR. A departure profile was therefore excluded at this weight.

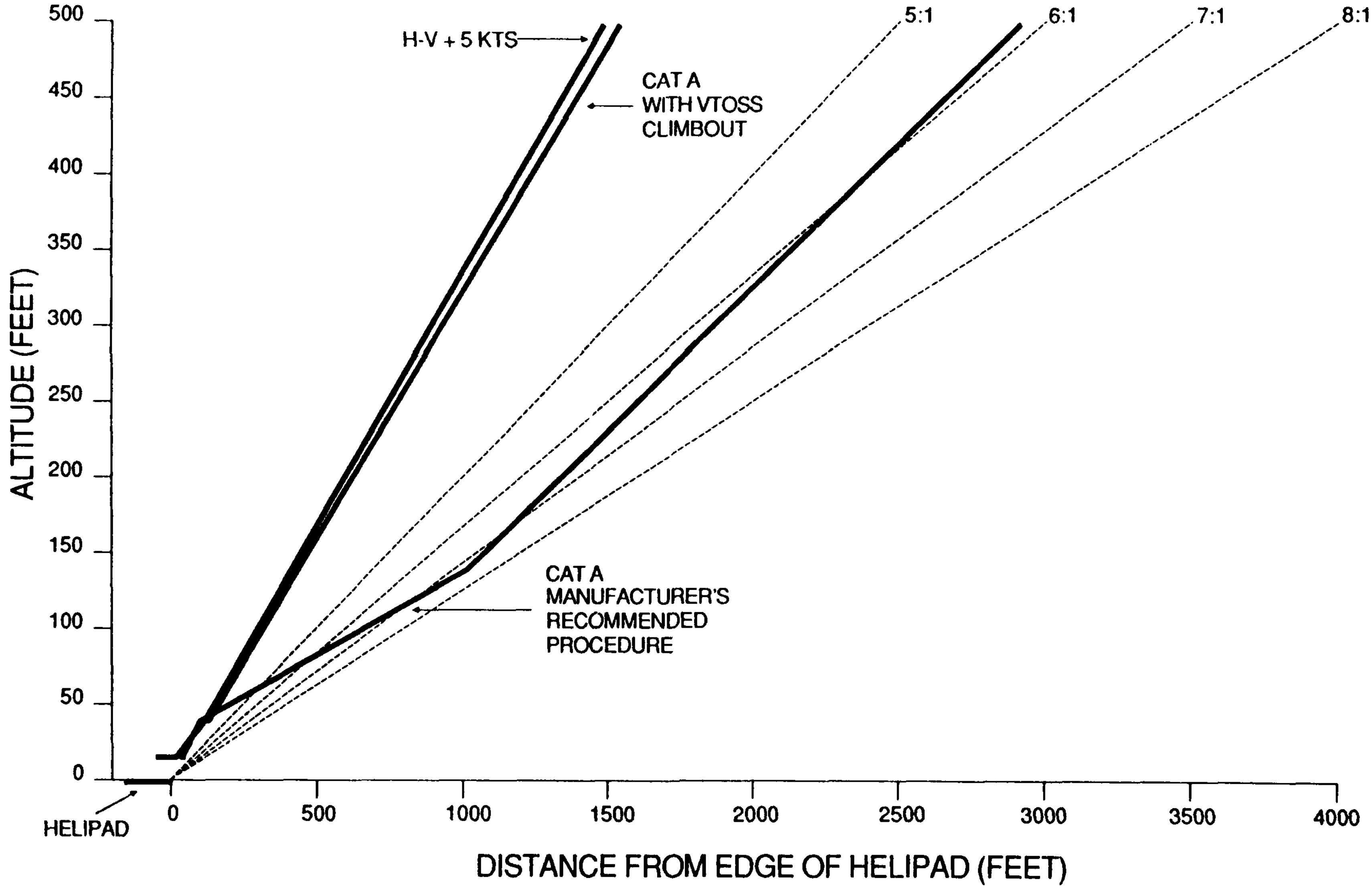
BV 234 LR DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL, STANDARD DAY



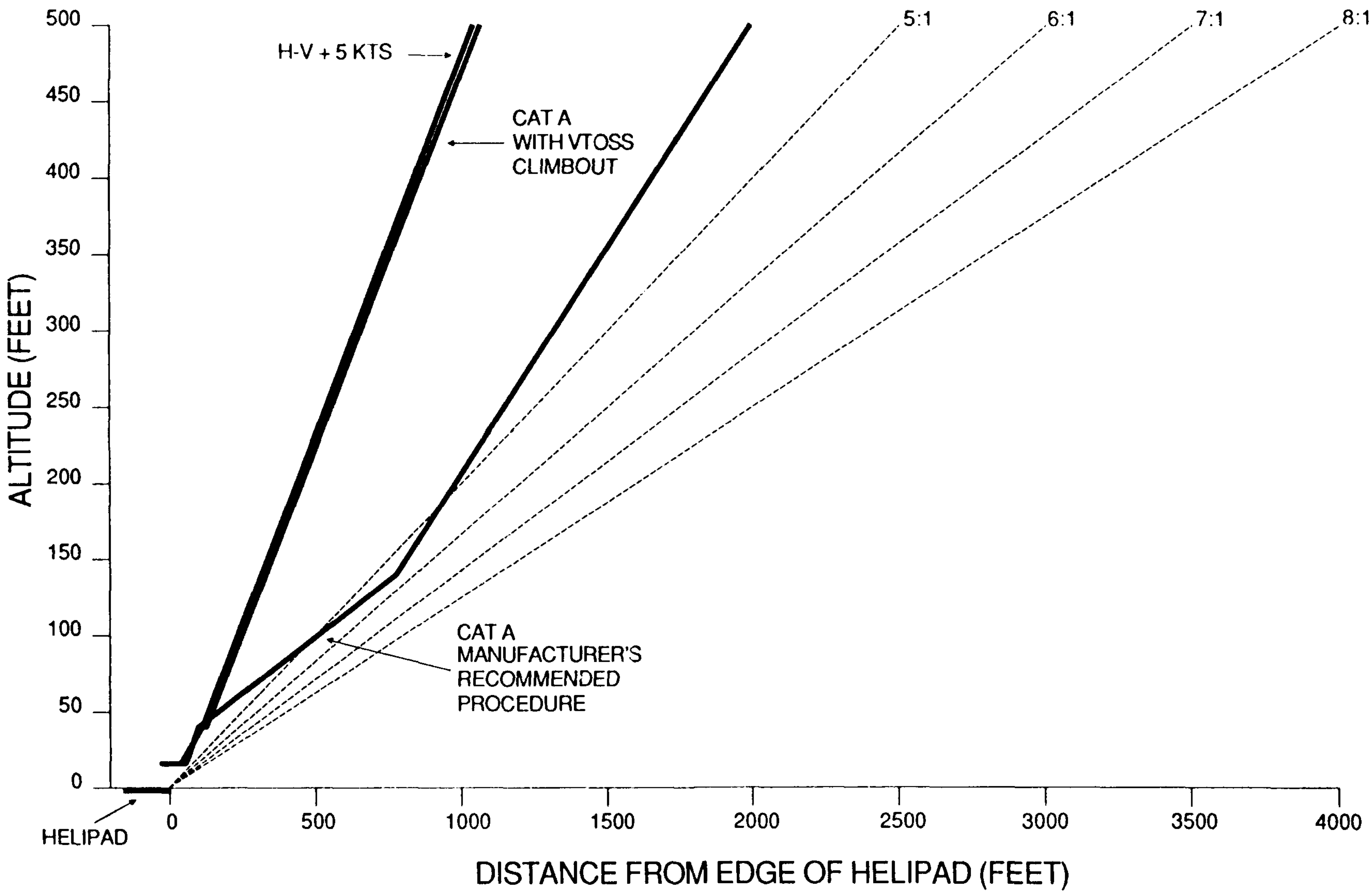
BV 234 LR DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL., HOT DAY



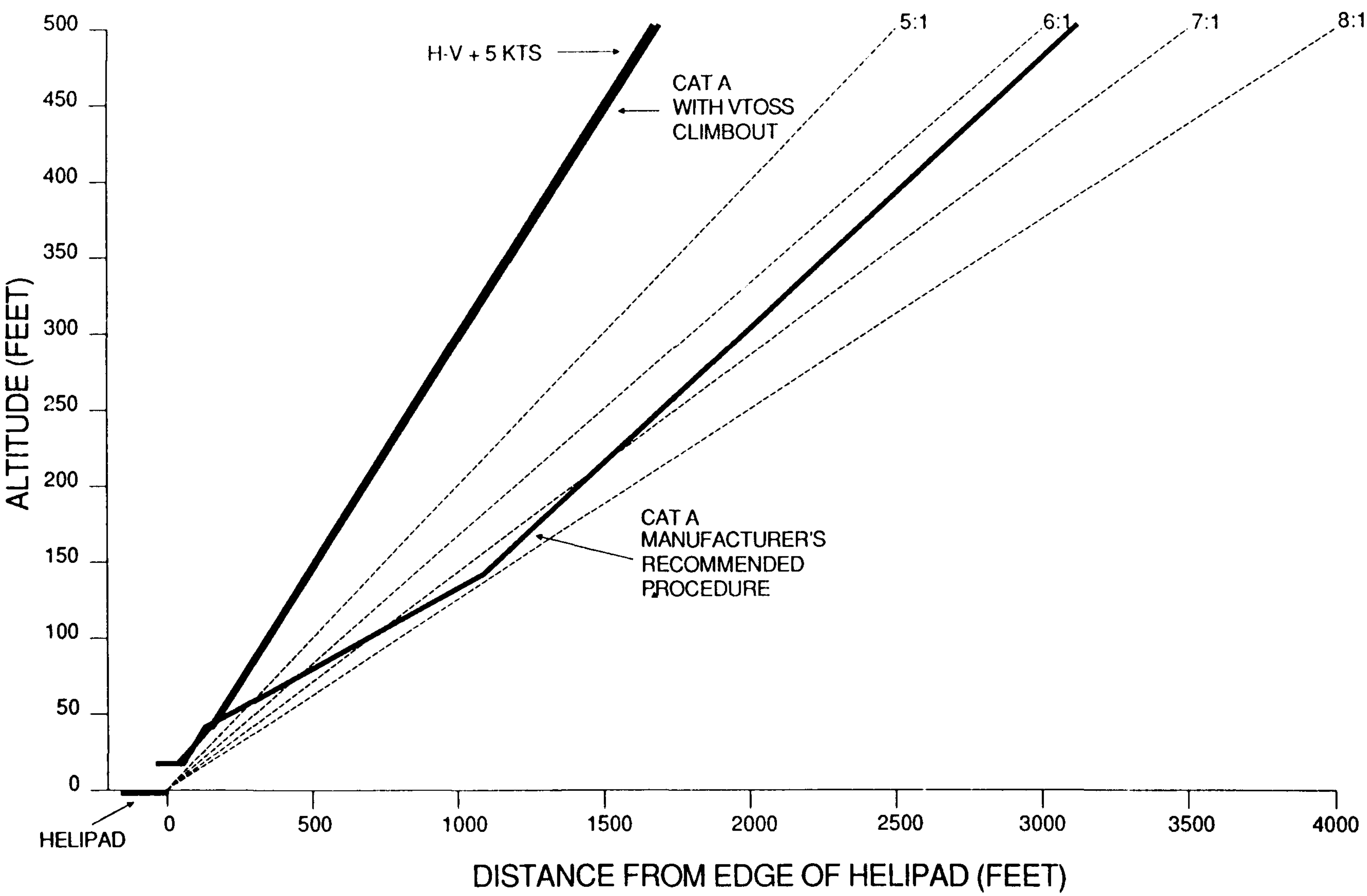
BV 234 LR DEPARTURE PROFILES

70% MAX. G.W., 2000 FEET, STANDARD DAY



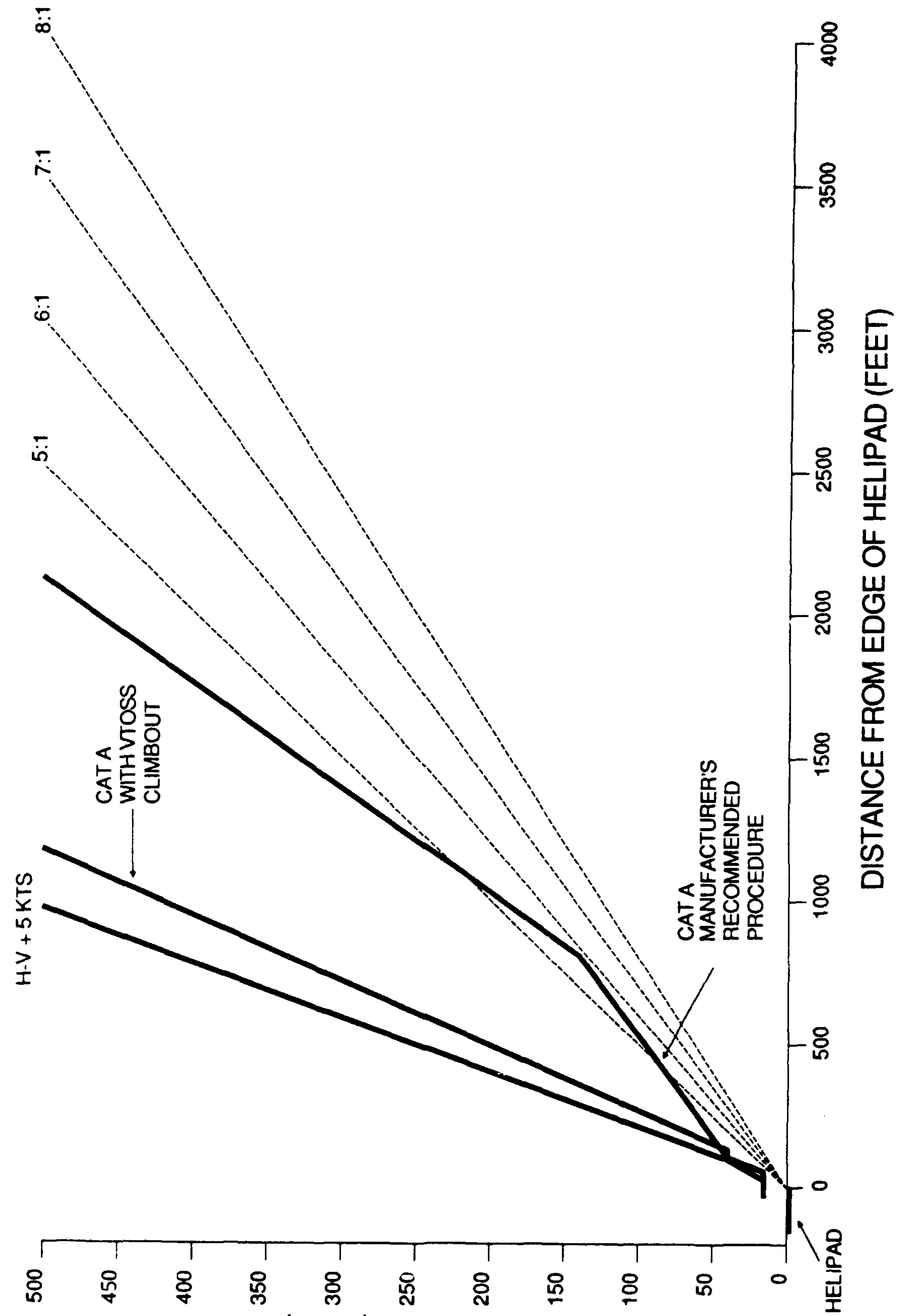
BV 234 LR DEPARTURE PROFILES

70% MAX. G.W., 2000 FEET, HOT DAY



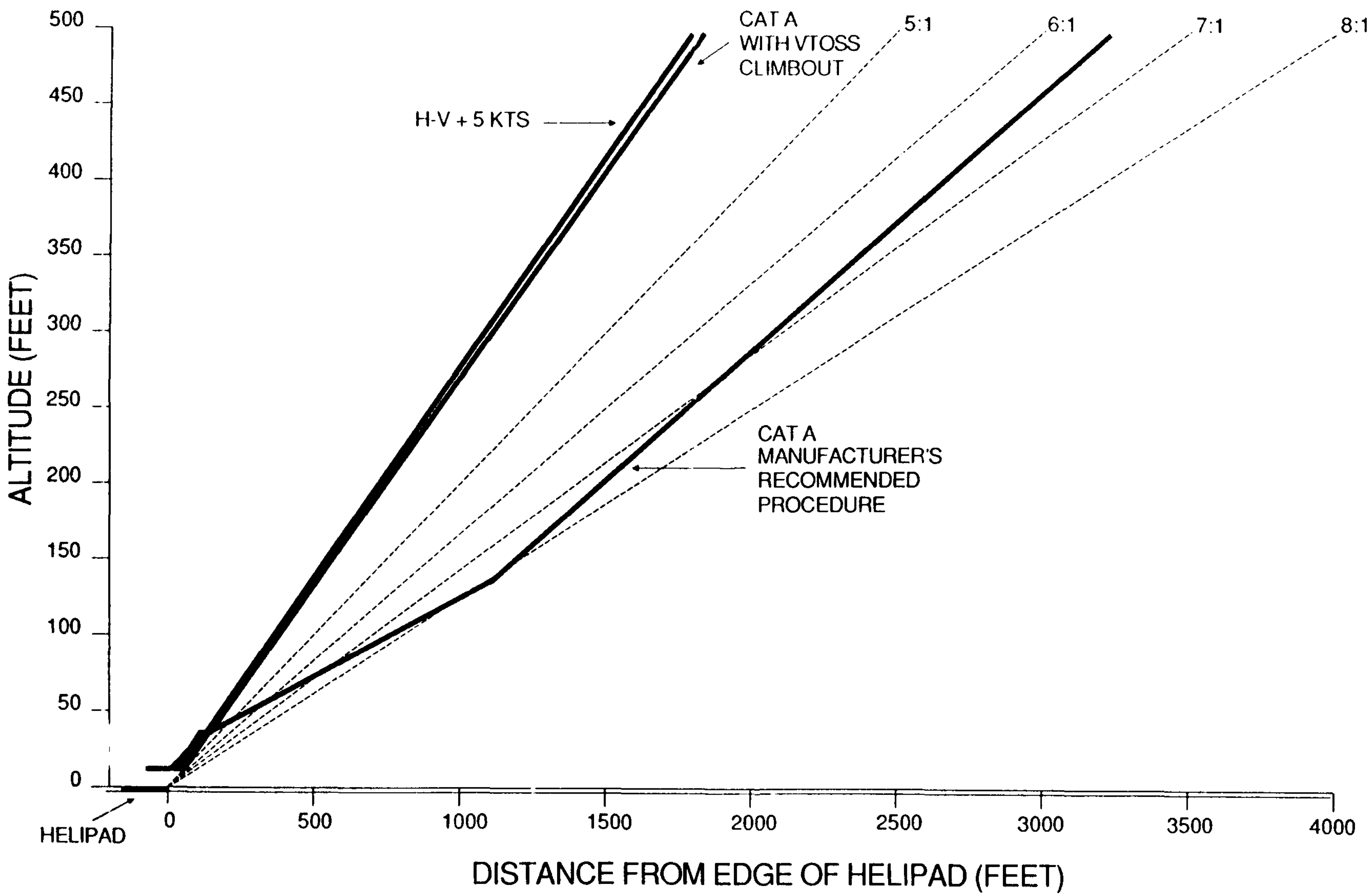
BV 234 LR DEPARTURE PROFILES

70% MAX. G.W., 4000 FEET, STANDARD DAY



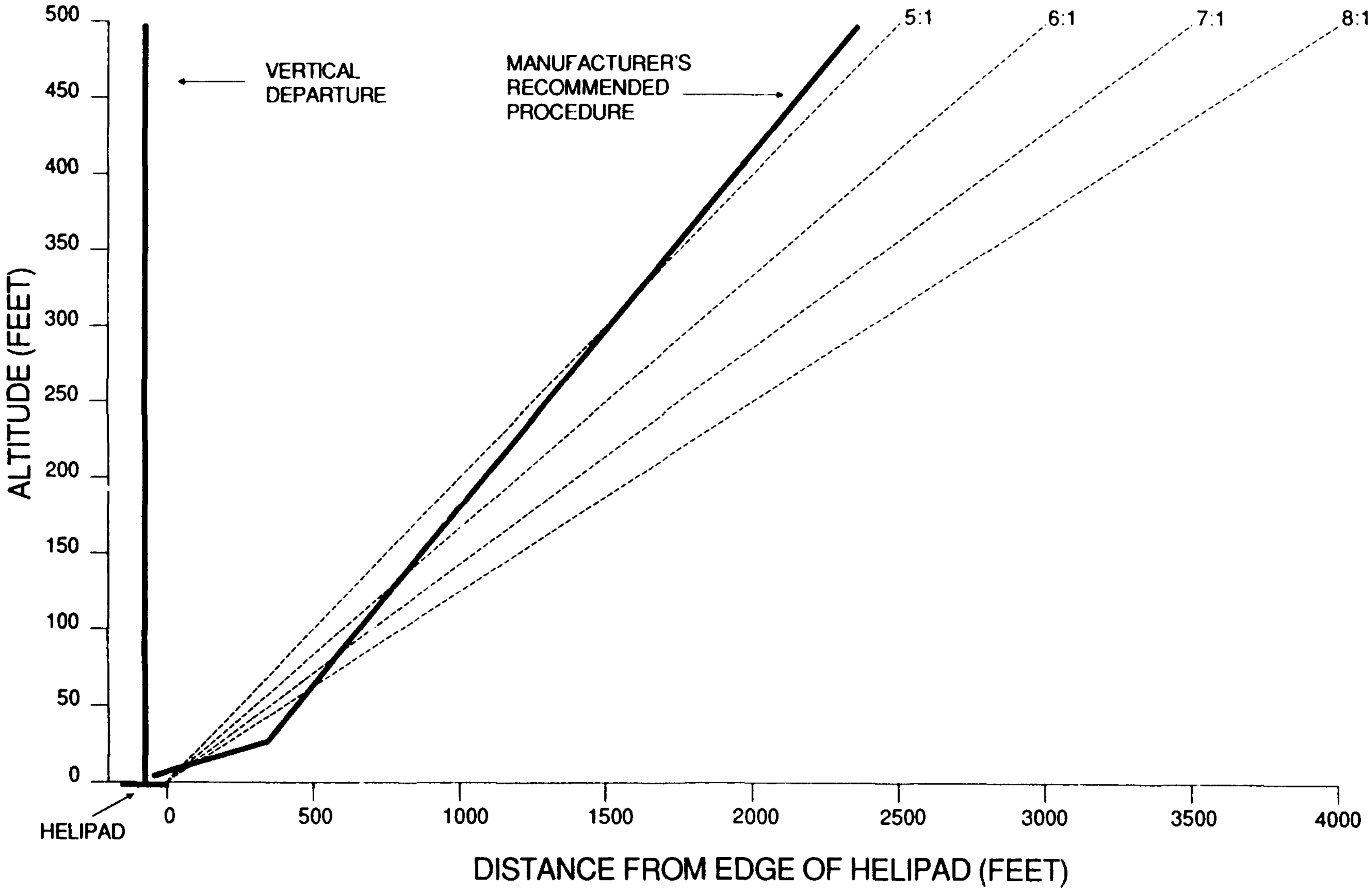
BV 234 LR DEPARTURE PROFILES

70% MAX. G.W., 4000 FEET, HOT DAY



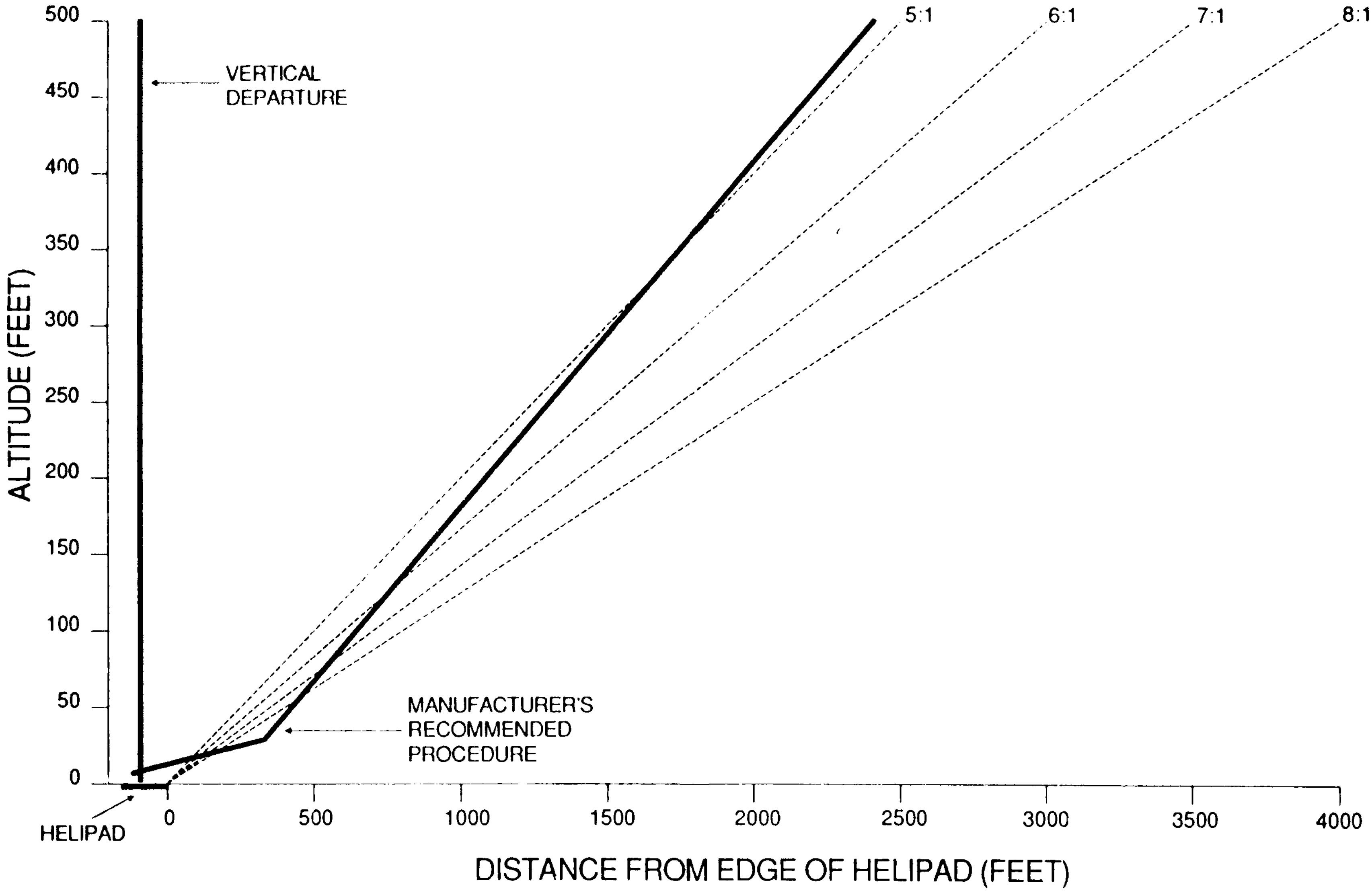
AS 355F DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, STANDARD DAY



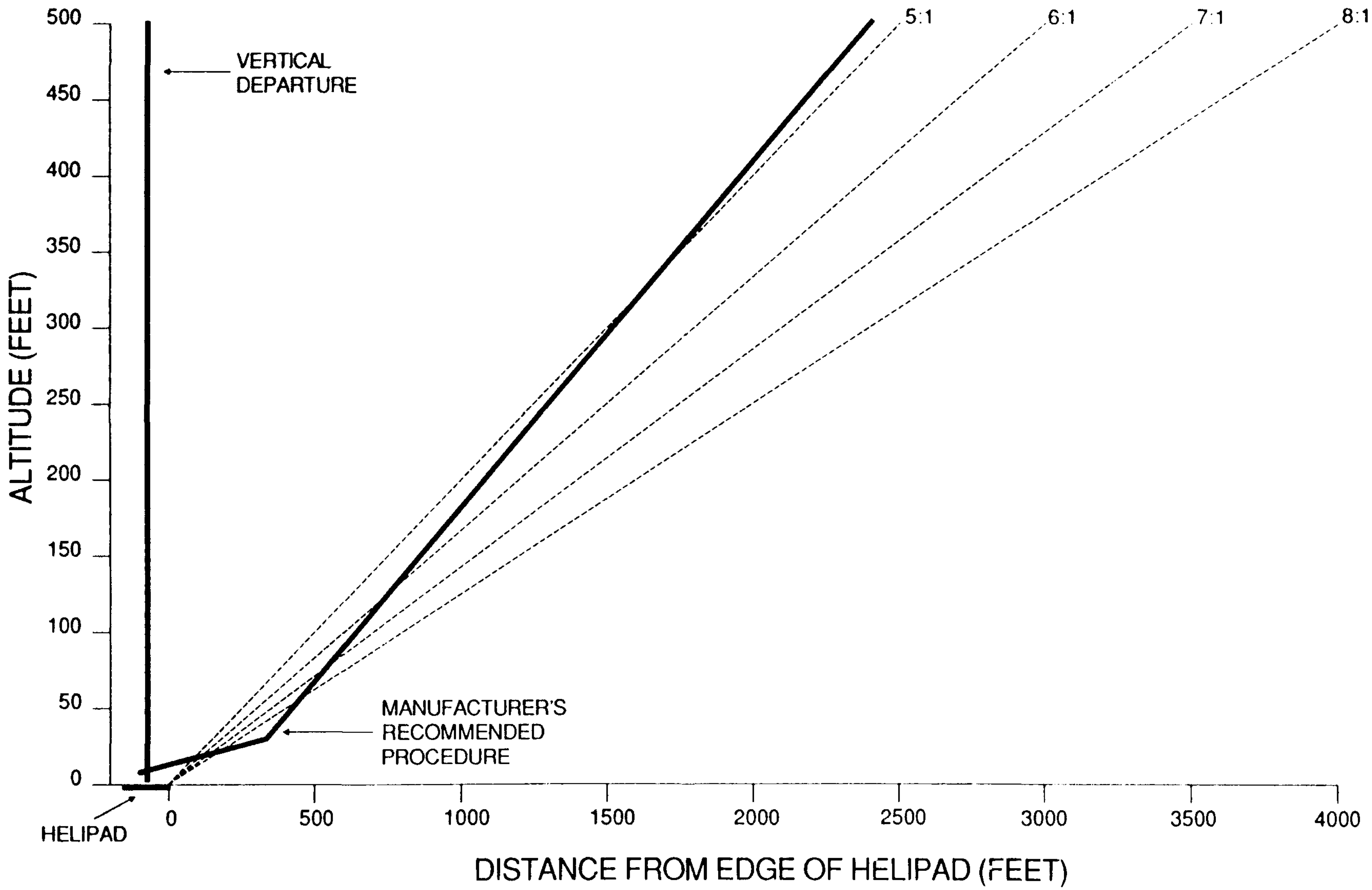
AS 355F DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, HOT DAY



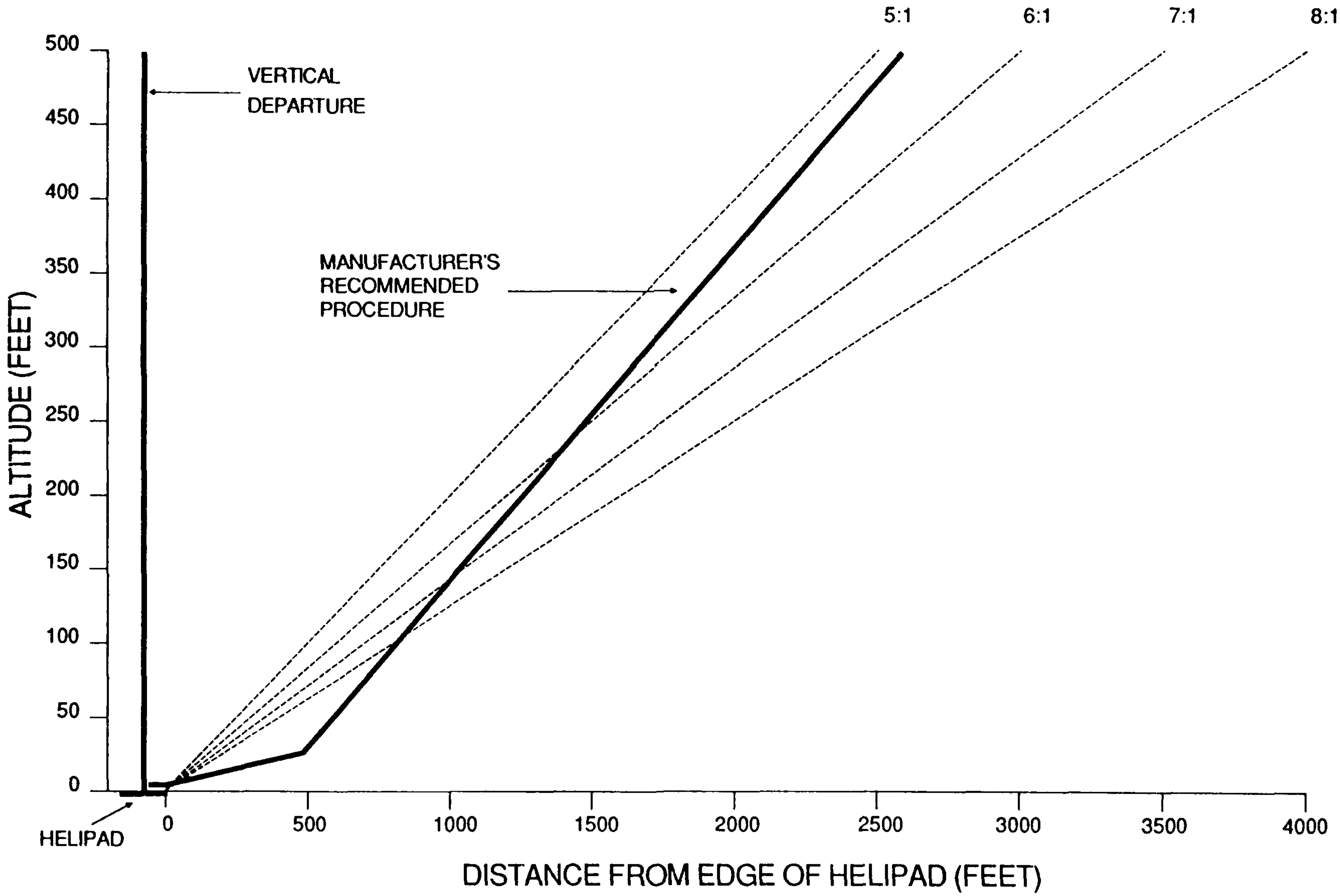
AS 355F DEPARTURE PROFILES

MAX. G.W., 2000 FEET, STANDARD DAY



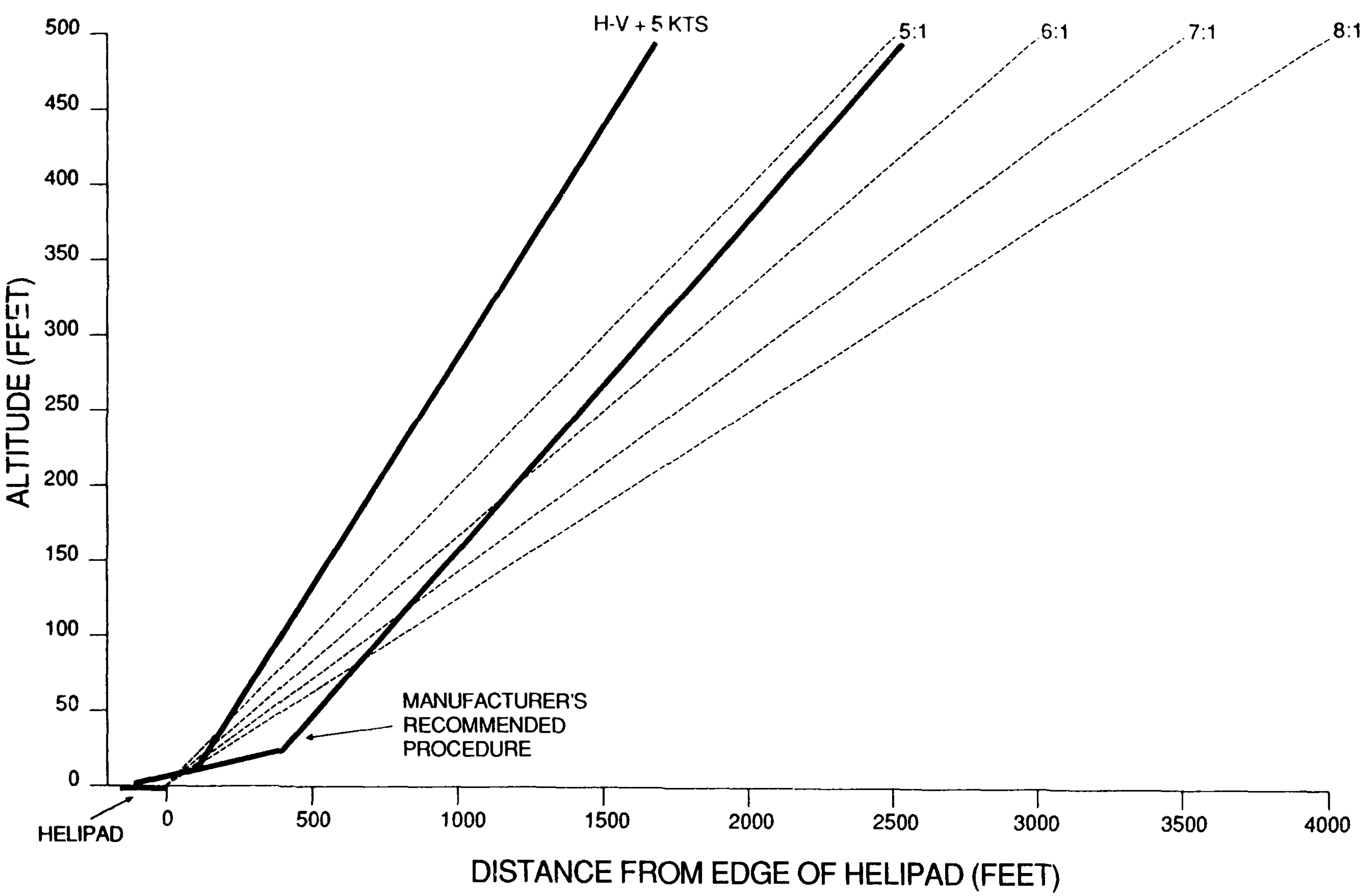
AS 355F DEPARTURE PROFILES

MAX. G.W., 2000 FEET, HOT DAY



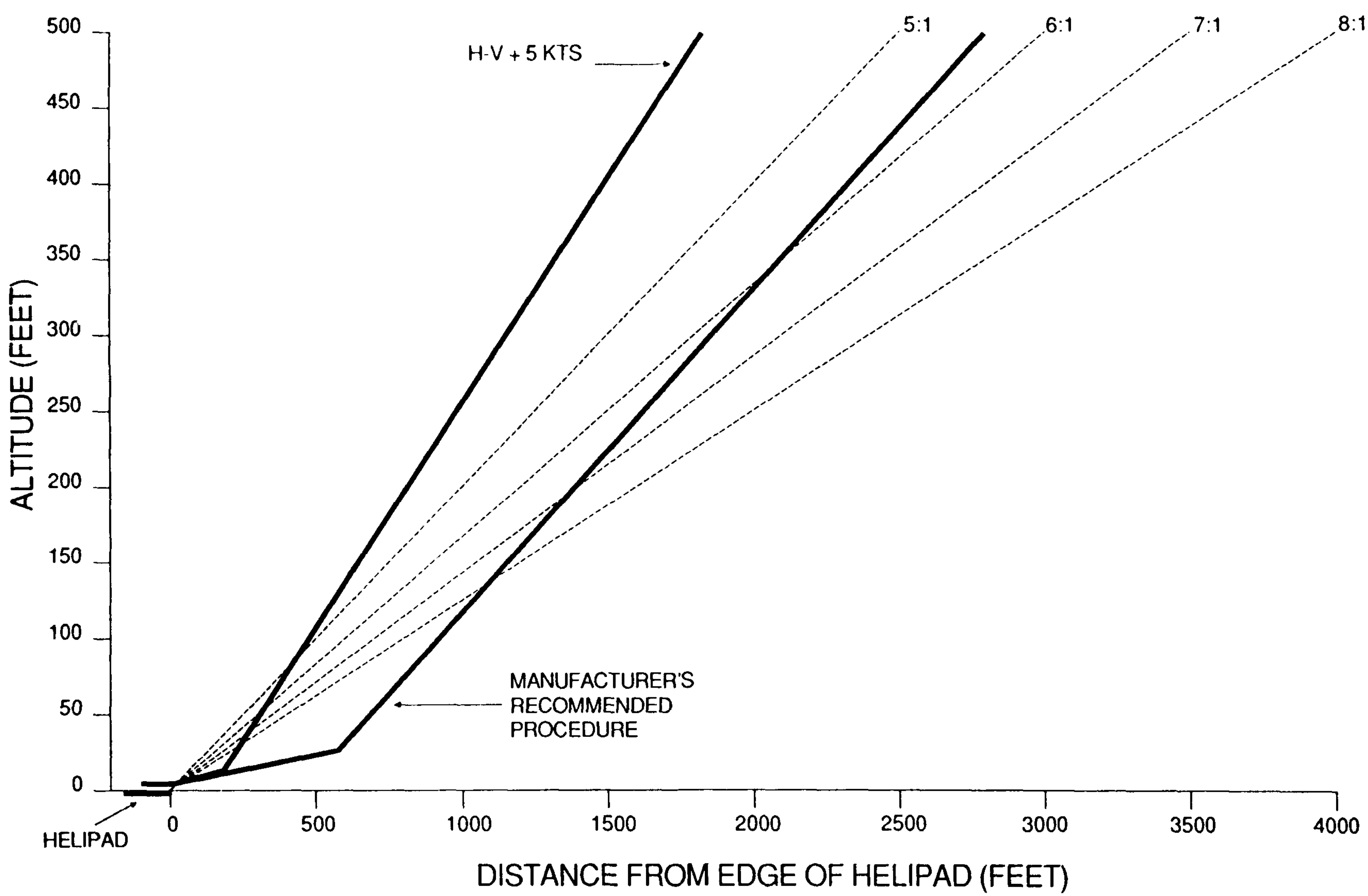
AS 355F DEPARTURE PROFILES

MAX. G.W., 4000 FEET, STANDARD DAY



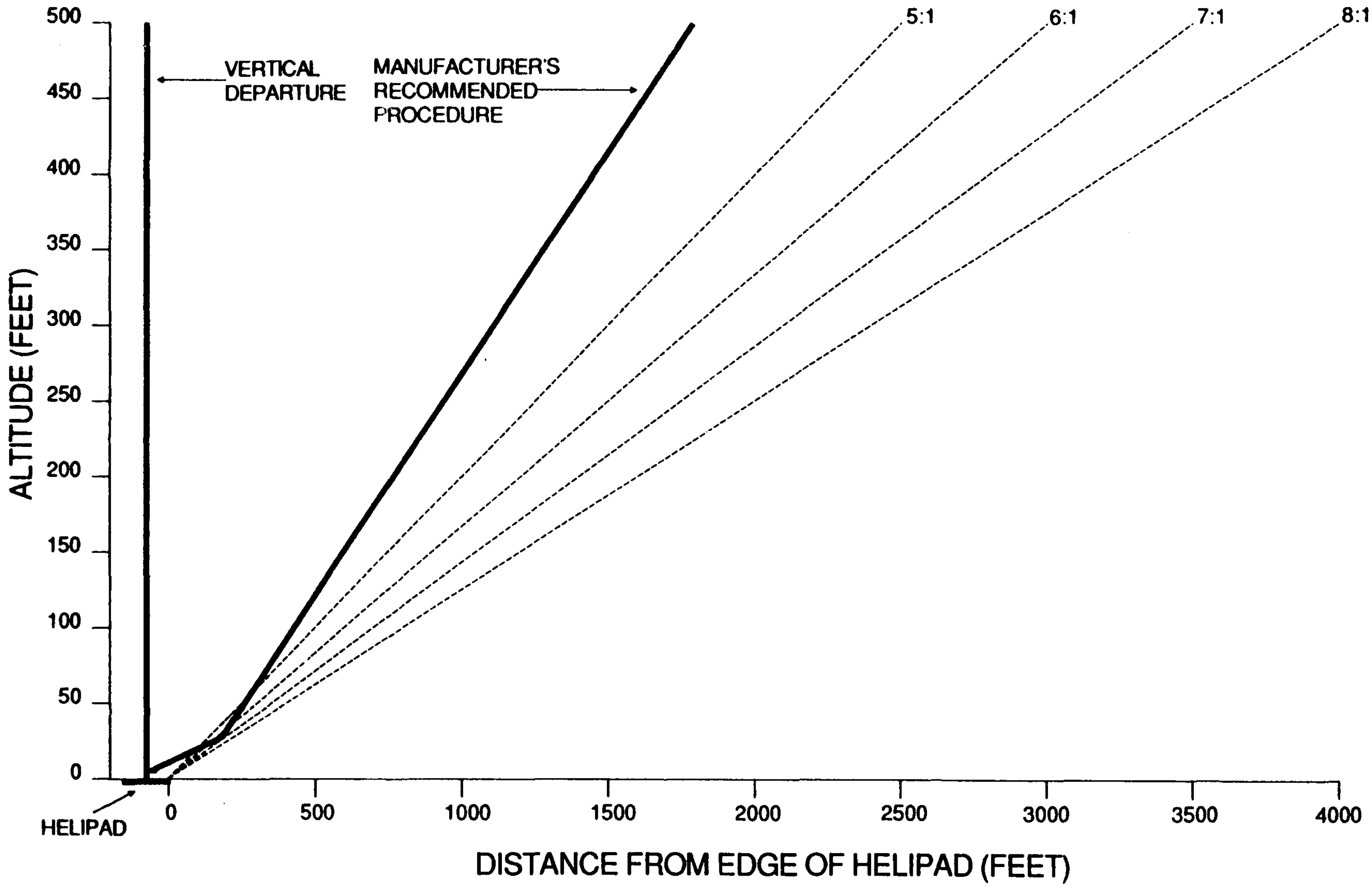
AS 355F DEPARTURE PROFILES

MAX. G.W., 4000 FEET, HOT DAY



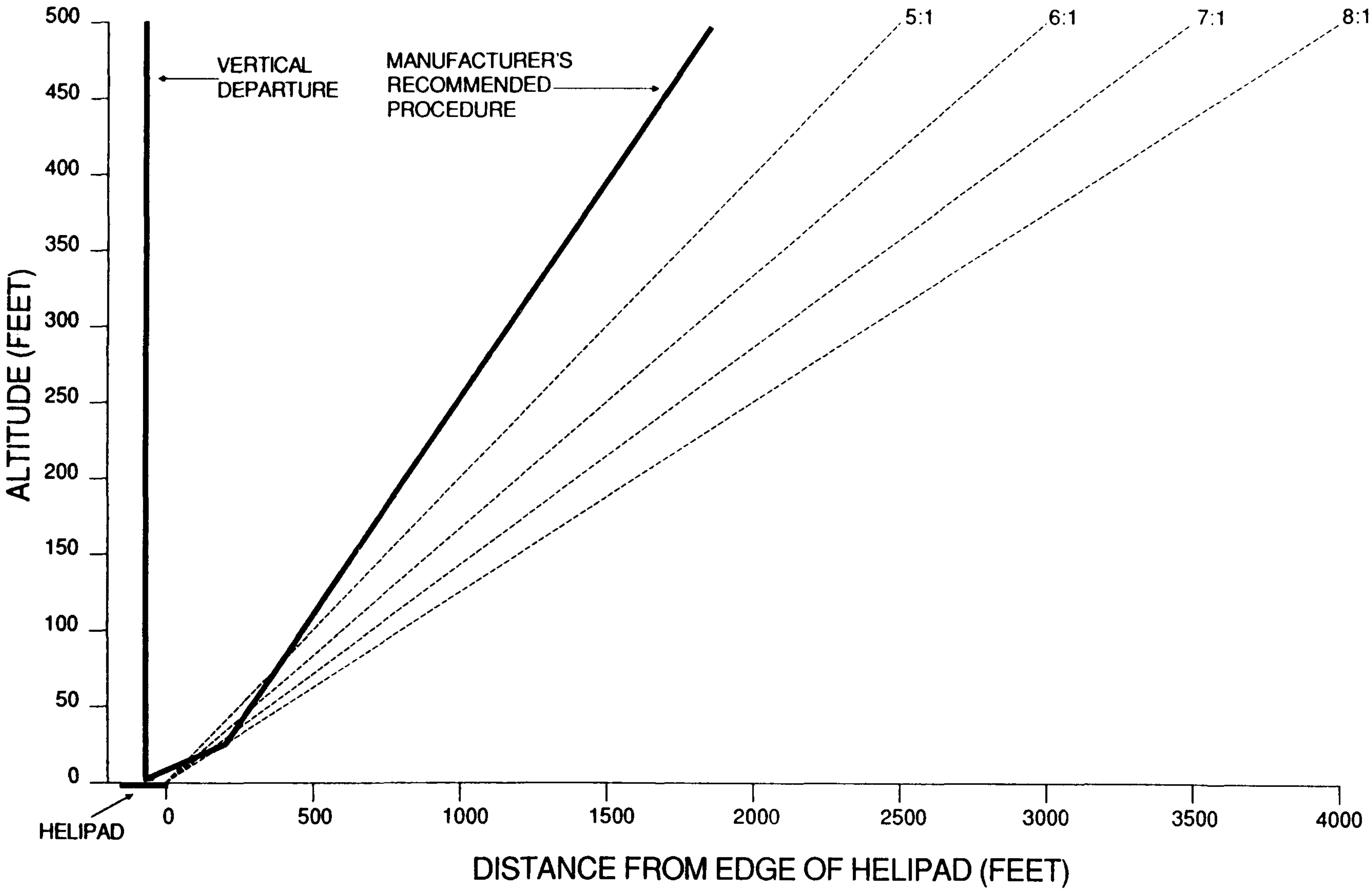
AS 355F DEPARTURE PROFILES

85% MAX. G.W., SEA LEVEL, STANDARD DAY



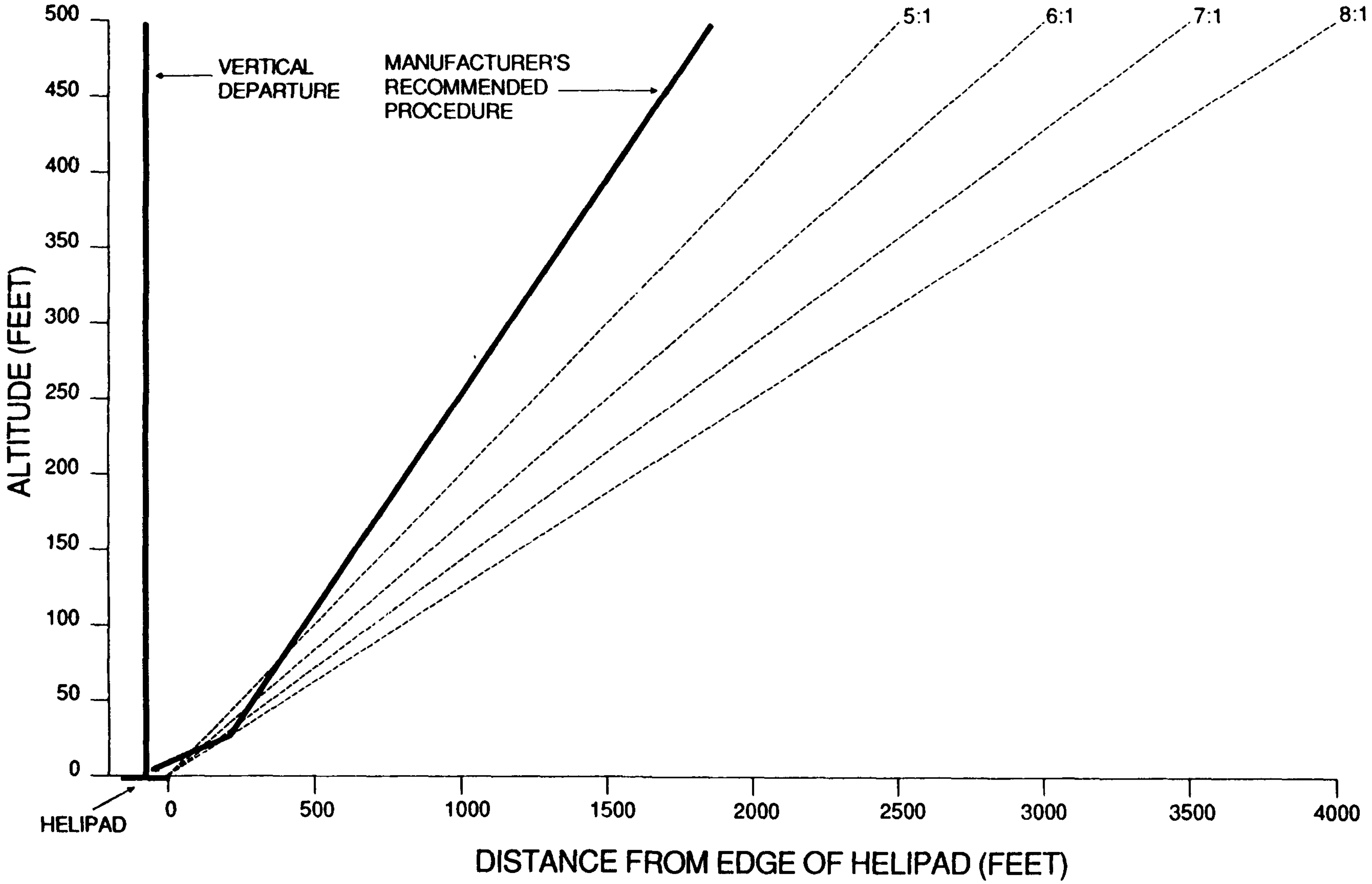
AS 355F DEPARTURE PROFILES

85% MAX. G.W., SEA LEVEL HOT DAY



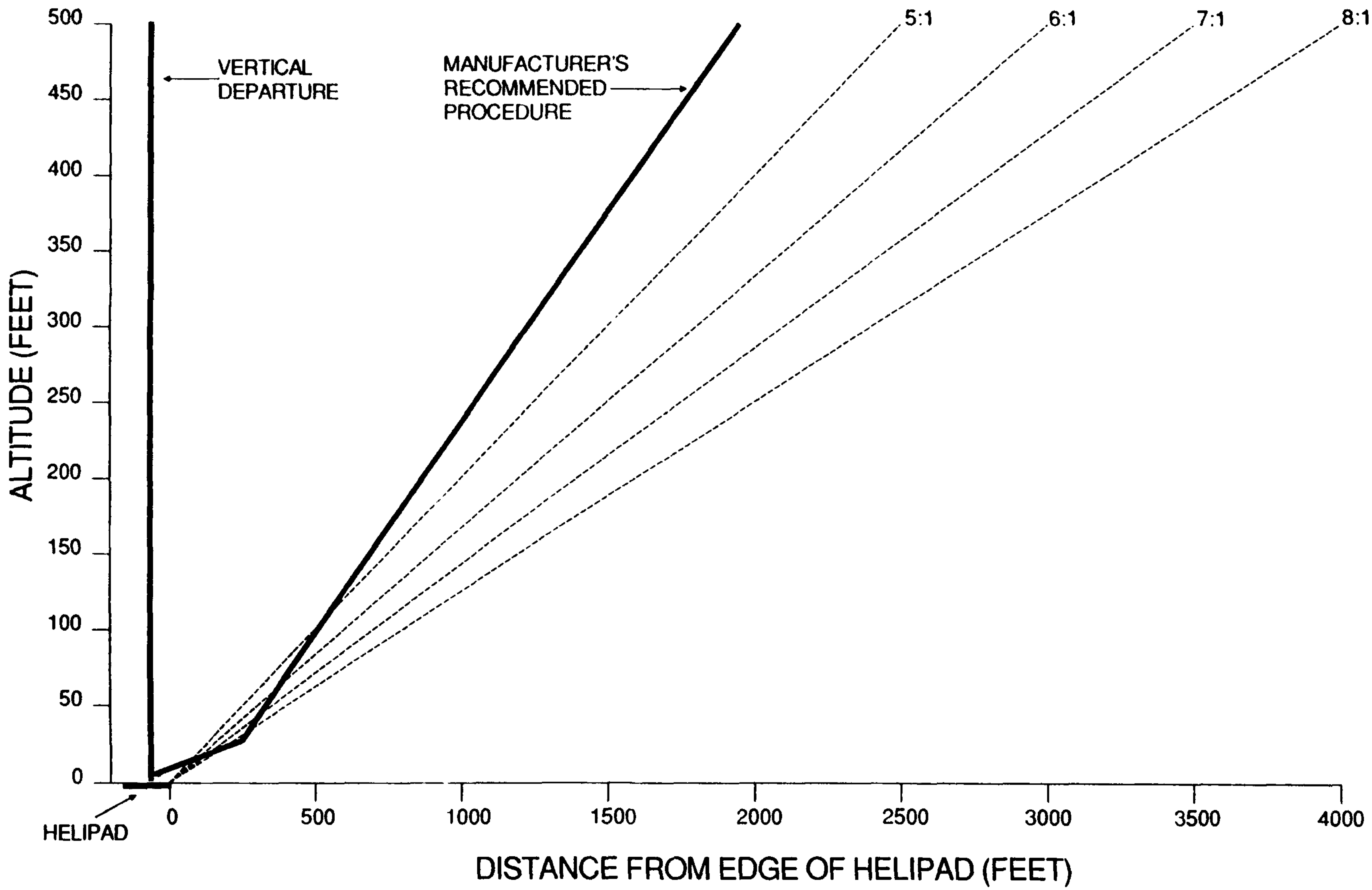
AS 355F DEPARTURE PROFILES

85% MAX. G.W., 2000 FEET, STANDARD DAY



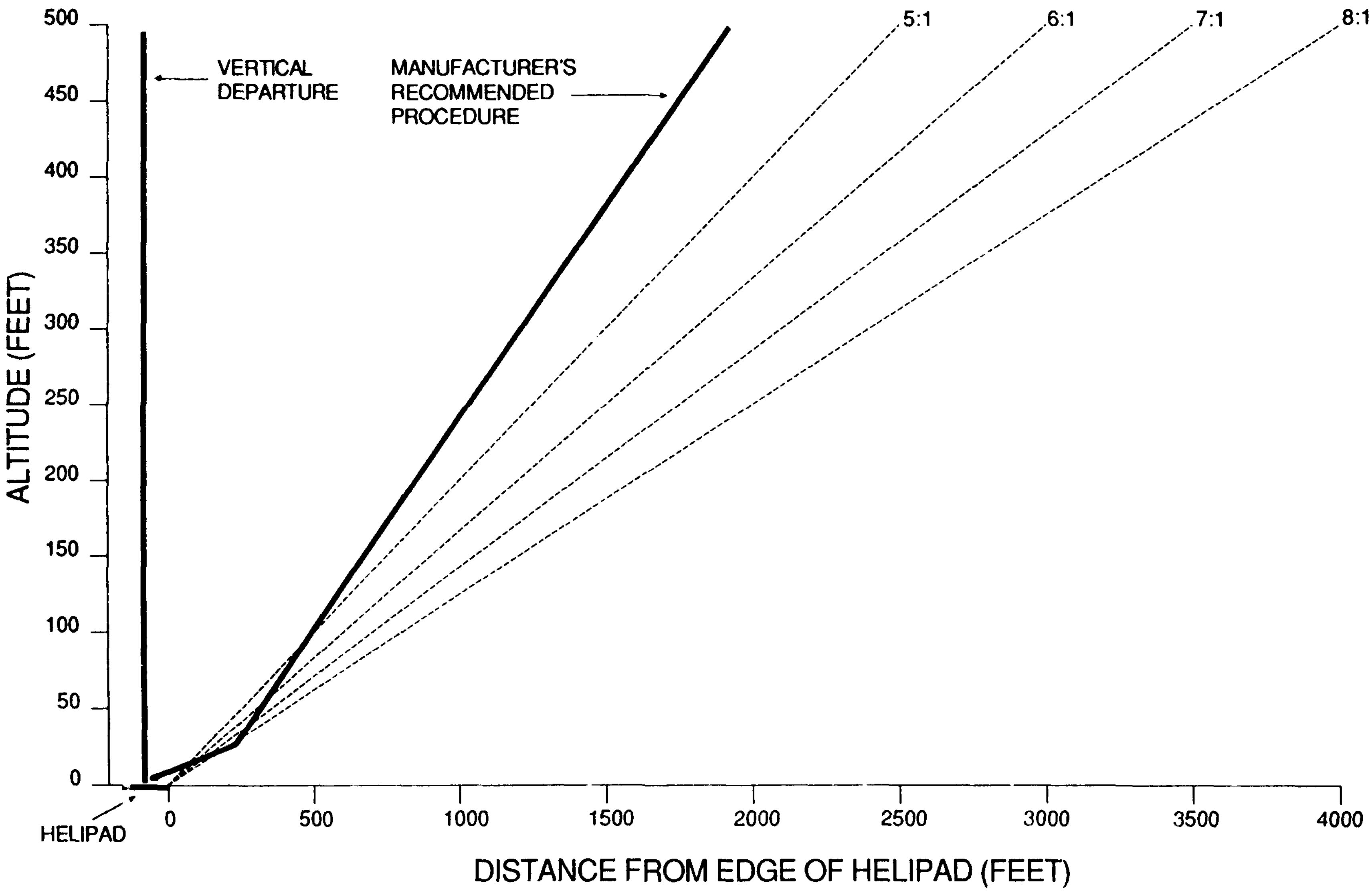
AS 355F DEPARTURE PROFILES

85% MAX. G.W., 2000 FEEET, HOT DAY



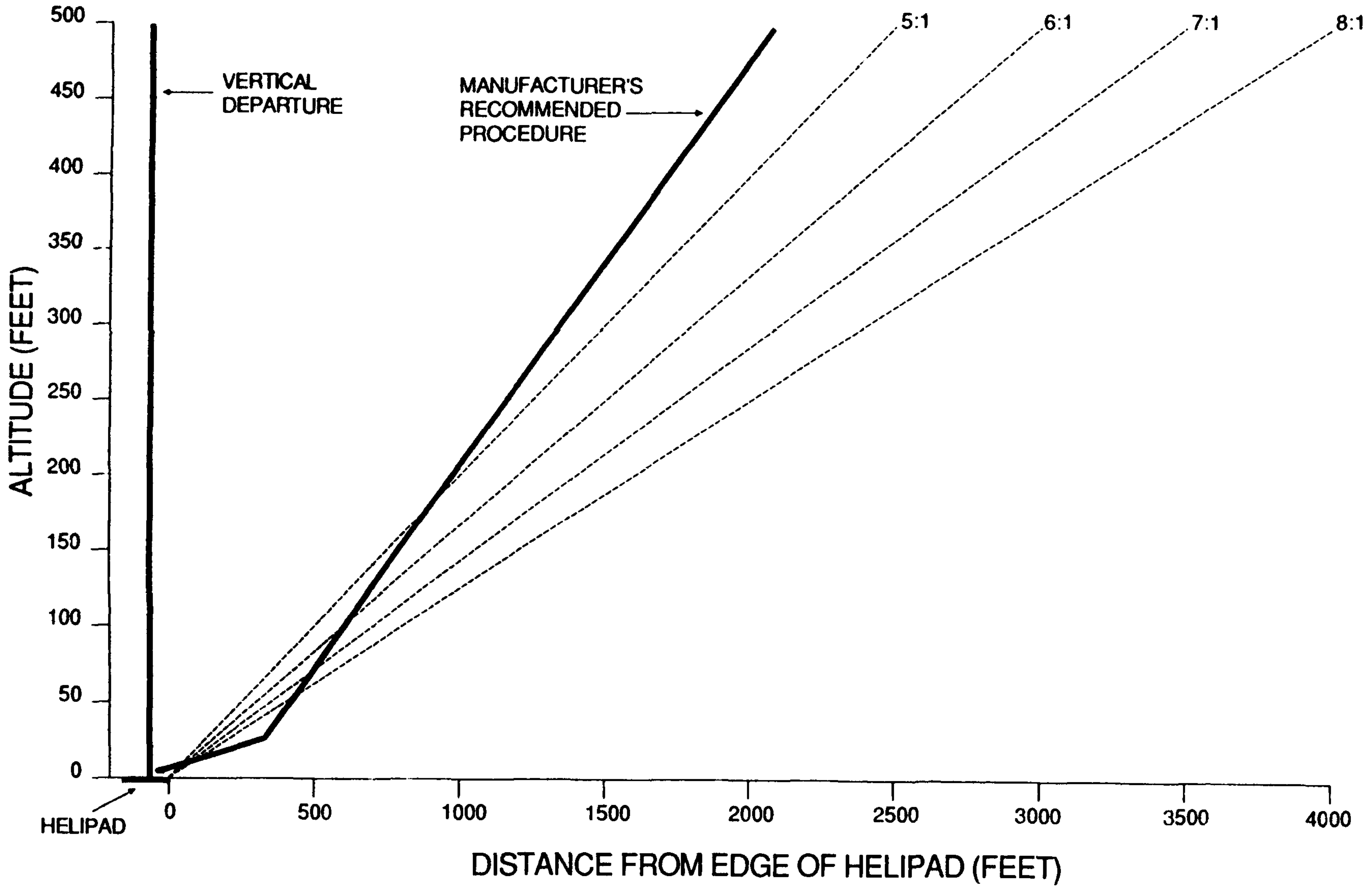
AS 355F DEPARTURE PROFILES

85% MAX. G.W., 4000 FEET, STANDARD DAY



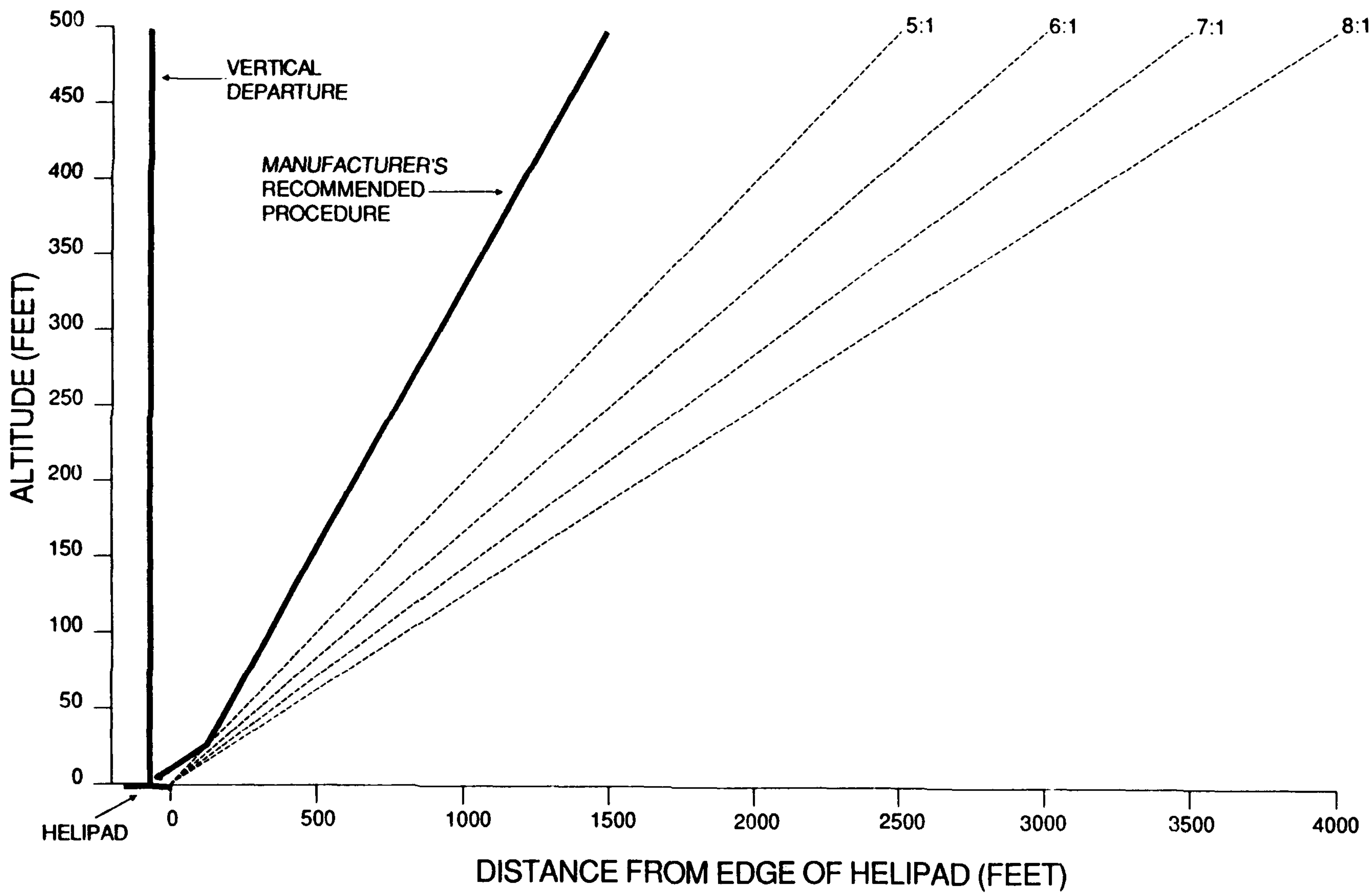
AS 355F DEPARTURE PROFILES

85% MAX. G.W., 4000 FEET, HOT DAY



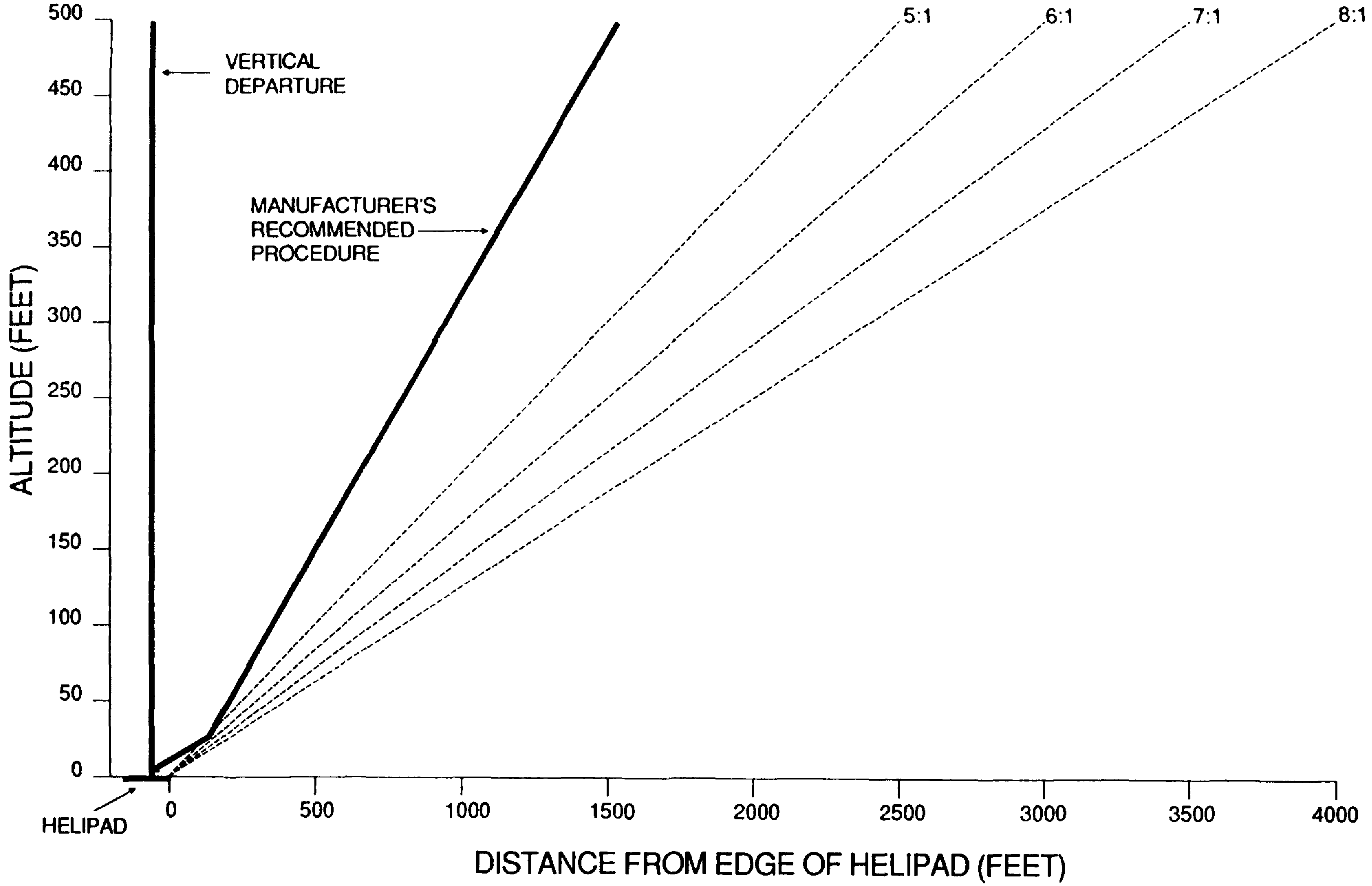
AS 355F DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL, STANDARD DAY



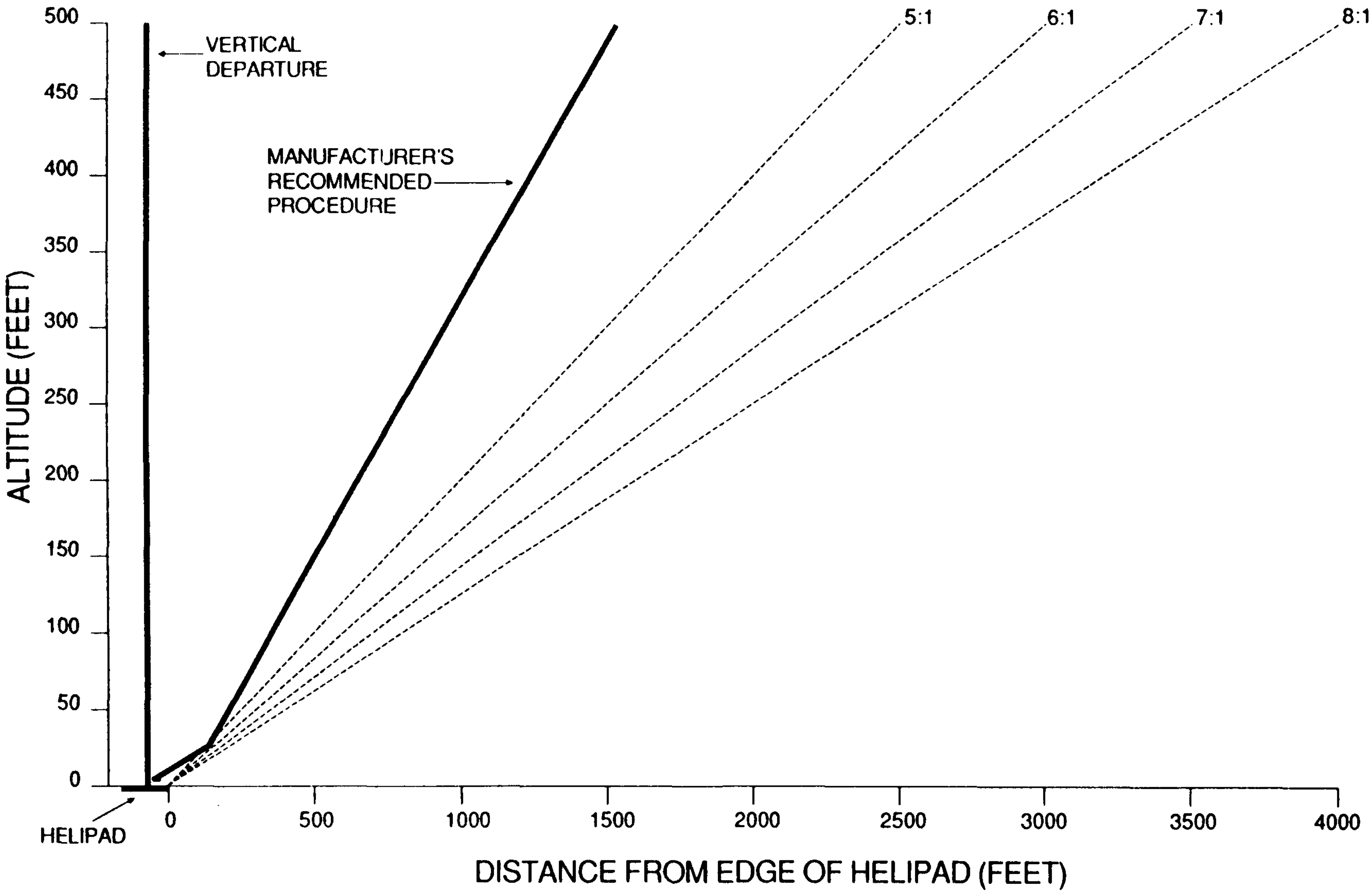
AS 355F DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL, HOT DAY



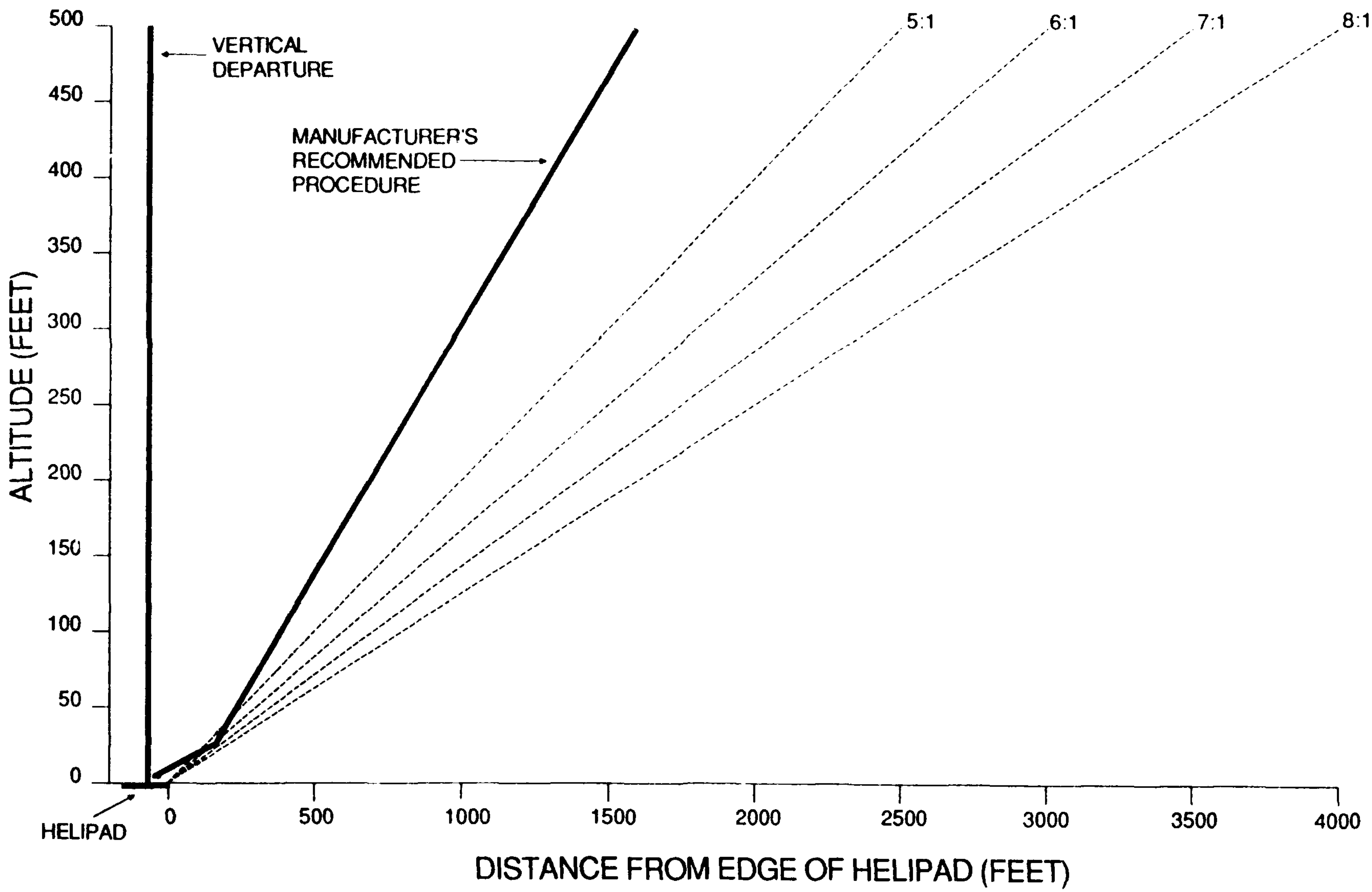
AS 355F DEPARTURE PROFILES

70% MAX G.W., 2000 FEET, STANDARD DAY



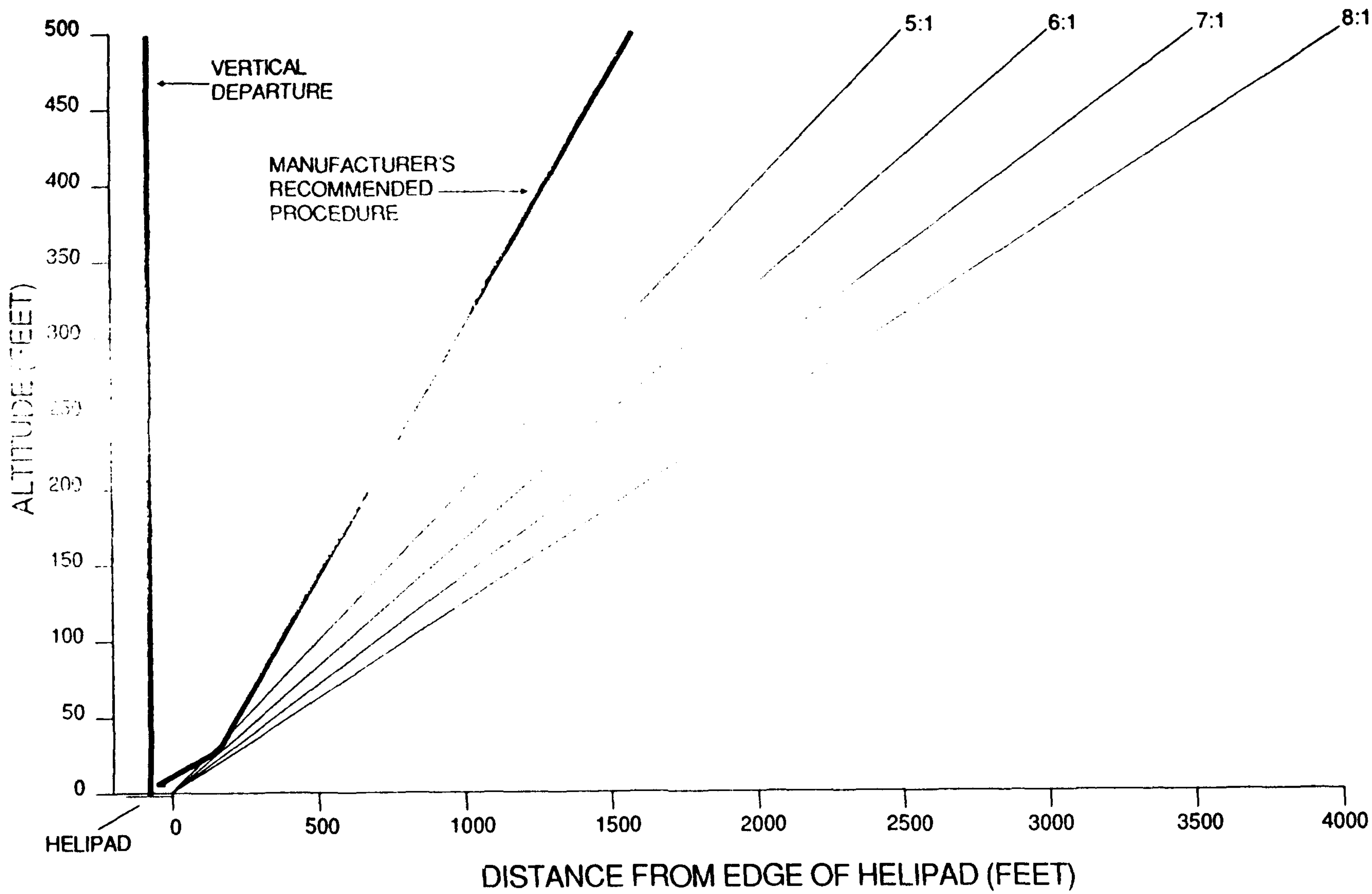
AS 355F DEPARTURE PROFILES

70% MAX. G.W., 2000 FEET, HOT DAY



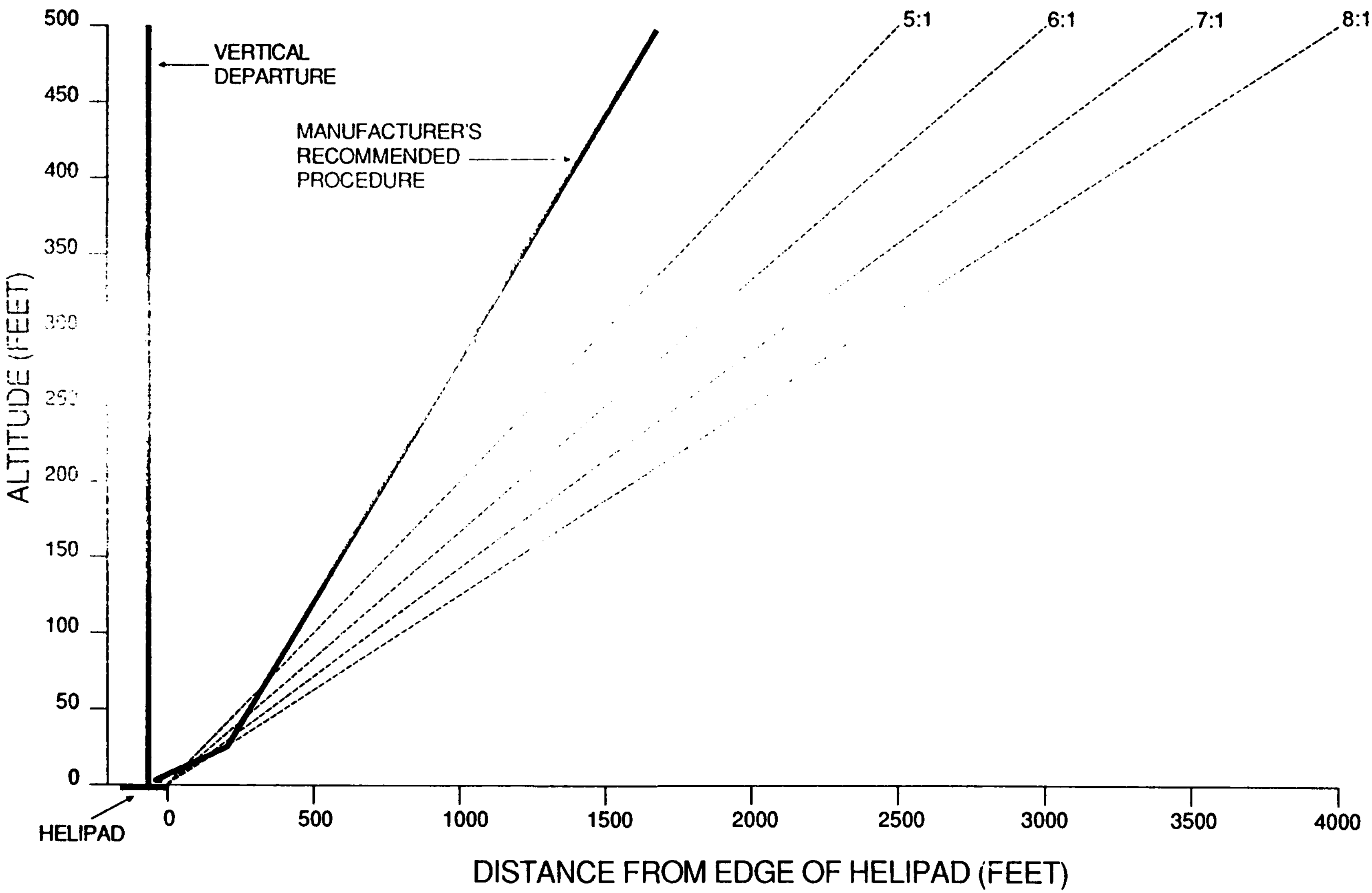
AS 355F DEPARTURE PROFILES

70% MAX. G.W., 4000 FEET, STANDARD DAY



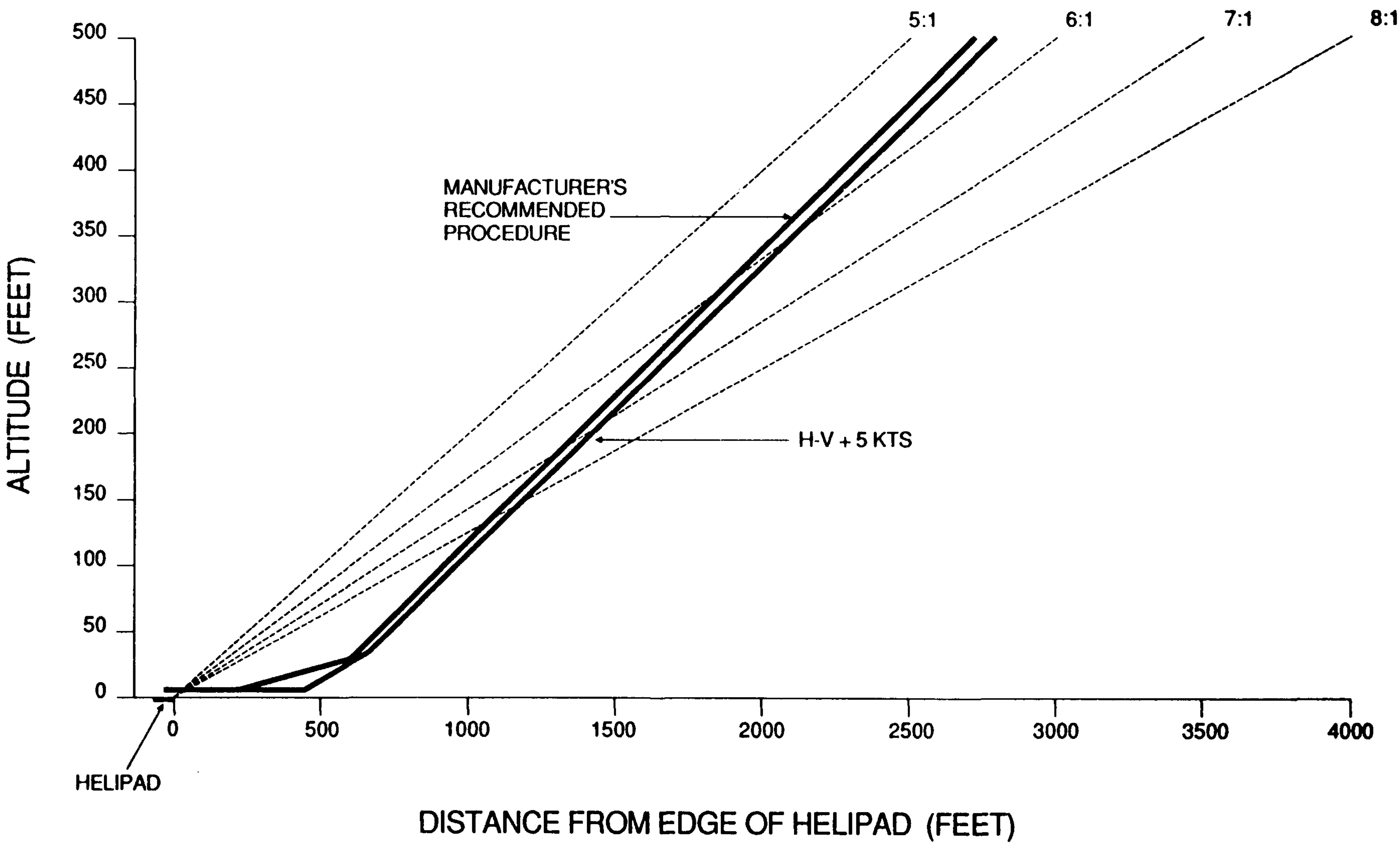
AS 355F DEPARTURE PROFILES

70% MAX. G.W., 4000 FEET, HOT DAY



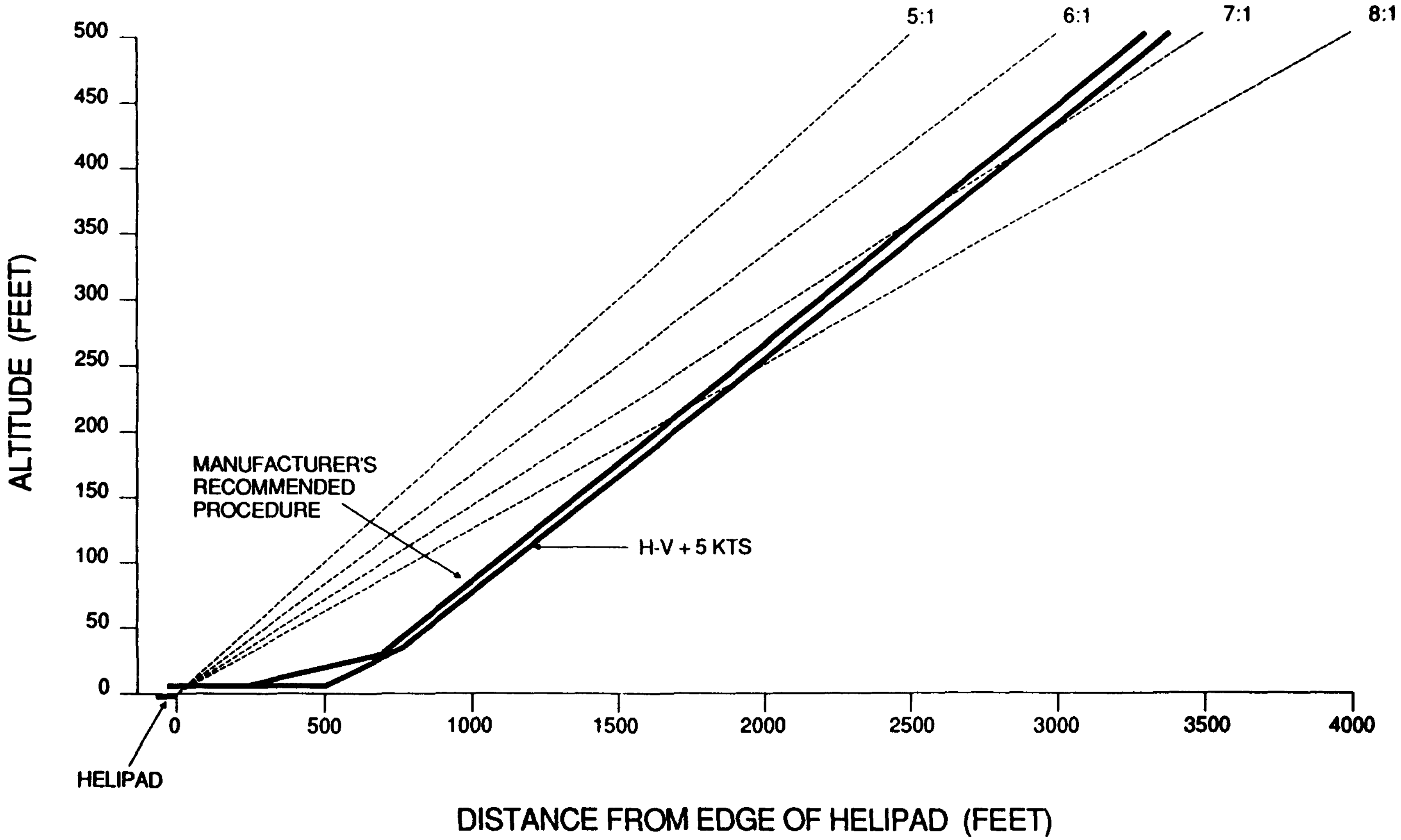
MBB BO 105 CBS DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, STANDARD DAY



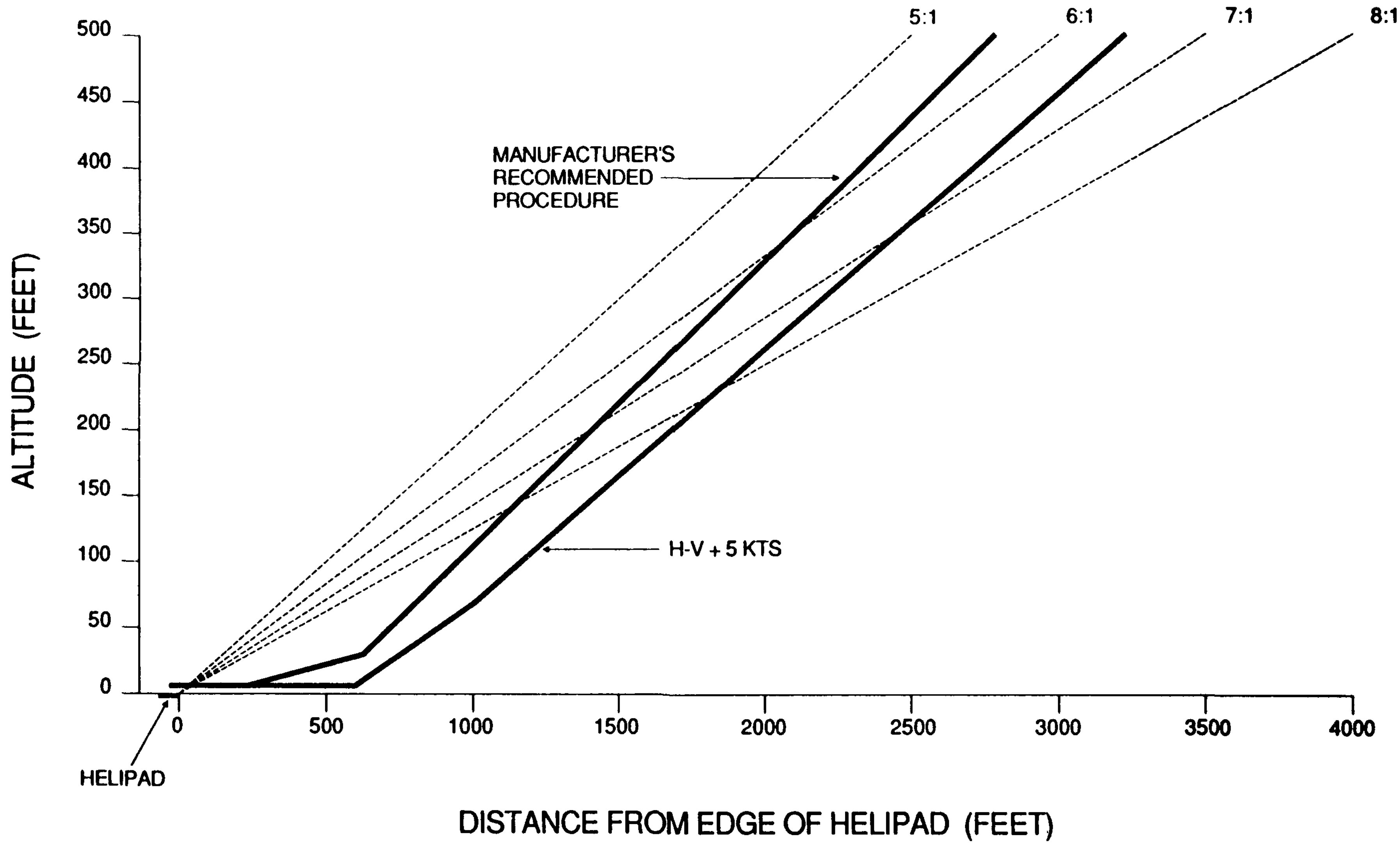
MBB BO 105 CBS DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, HOT DAY



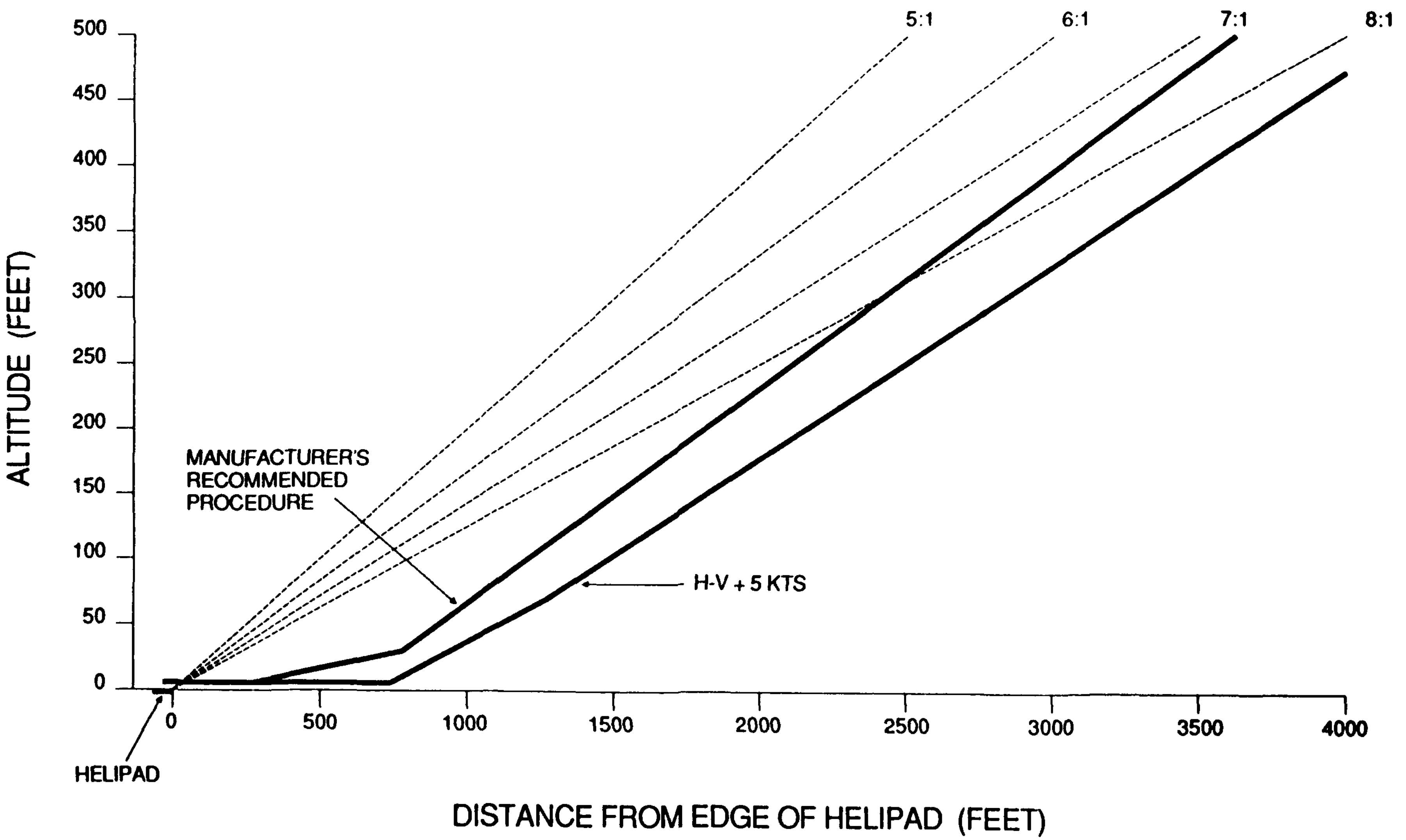
MBB BO 105 CBS DEPARTURE PROFILES

MAX. G.W., 2000 FEET, STANDARD DAY



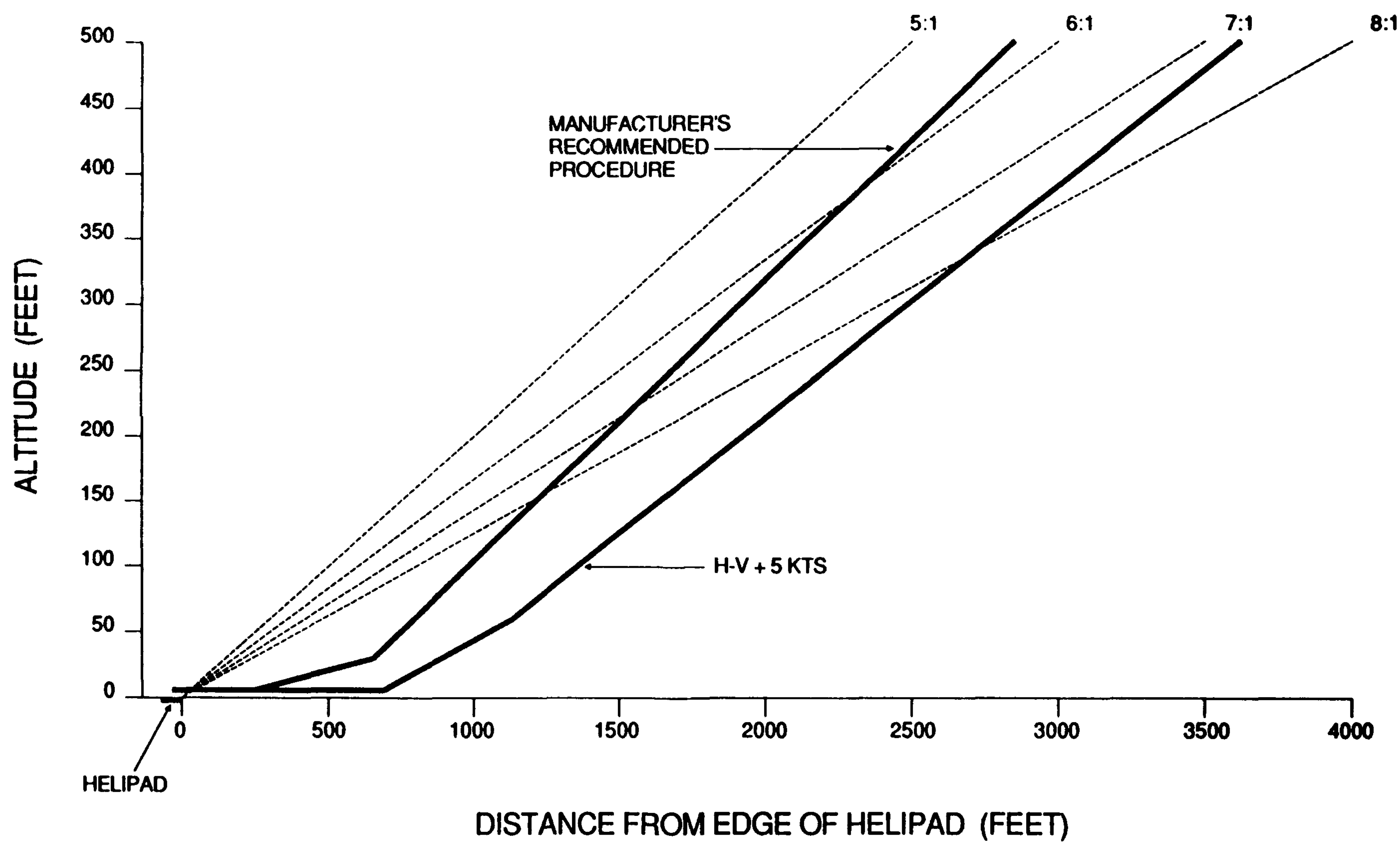
MBB BO 105 CBS DEPARTURE PROFILES

MAX. G.W., 2000 FEET, HOT DAY



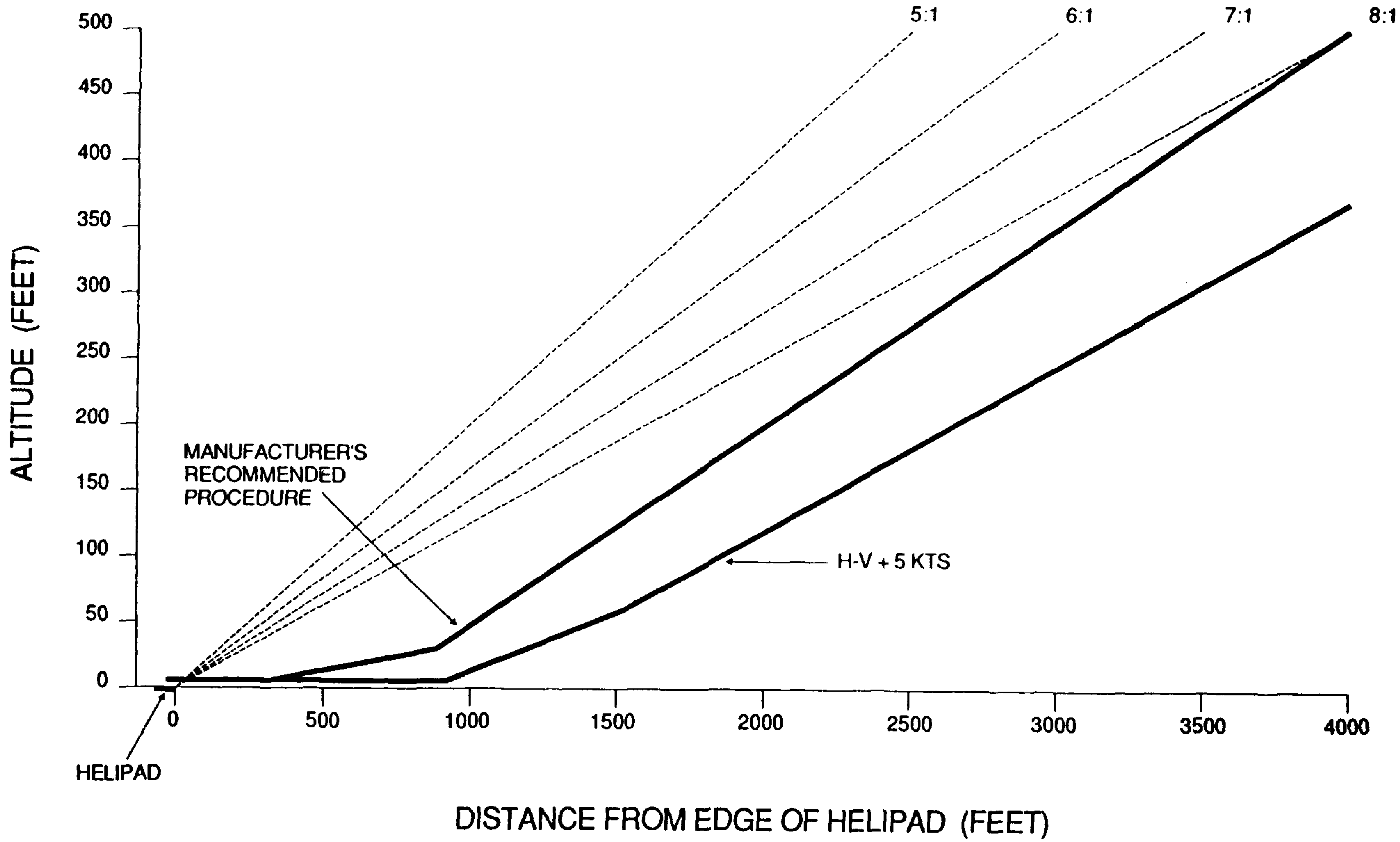
MBB BO 105 CBS DEPARTURE PROFILES

MAX. G.W., 4000 FEET, STANDARD DAY



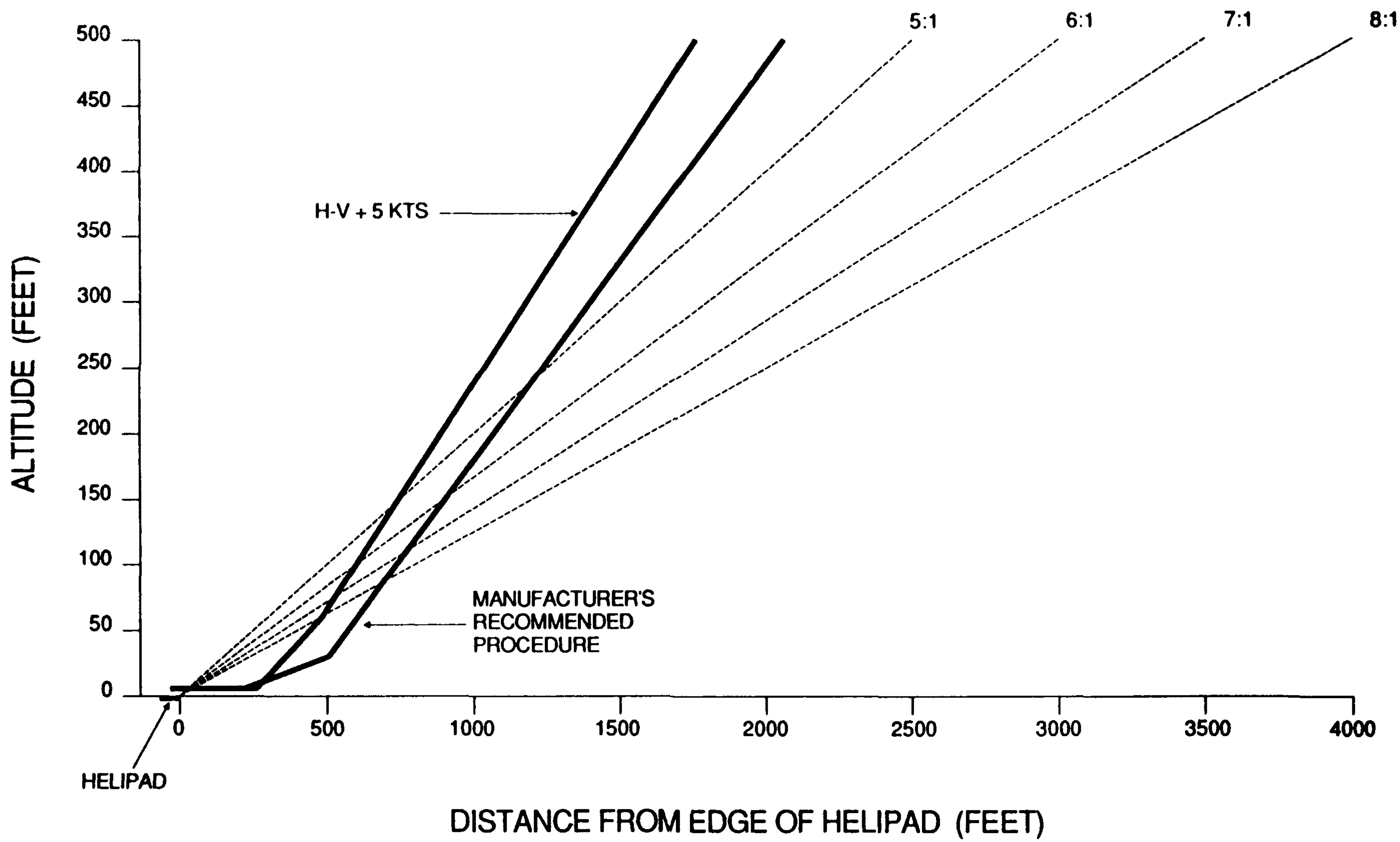
MBB BO 105 CBS DEPARTURE PROFILES

MAX. G.W., 4000 FEET, HOT DAY



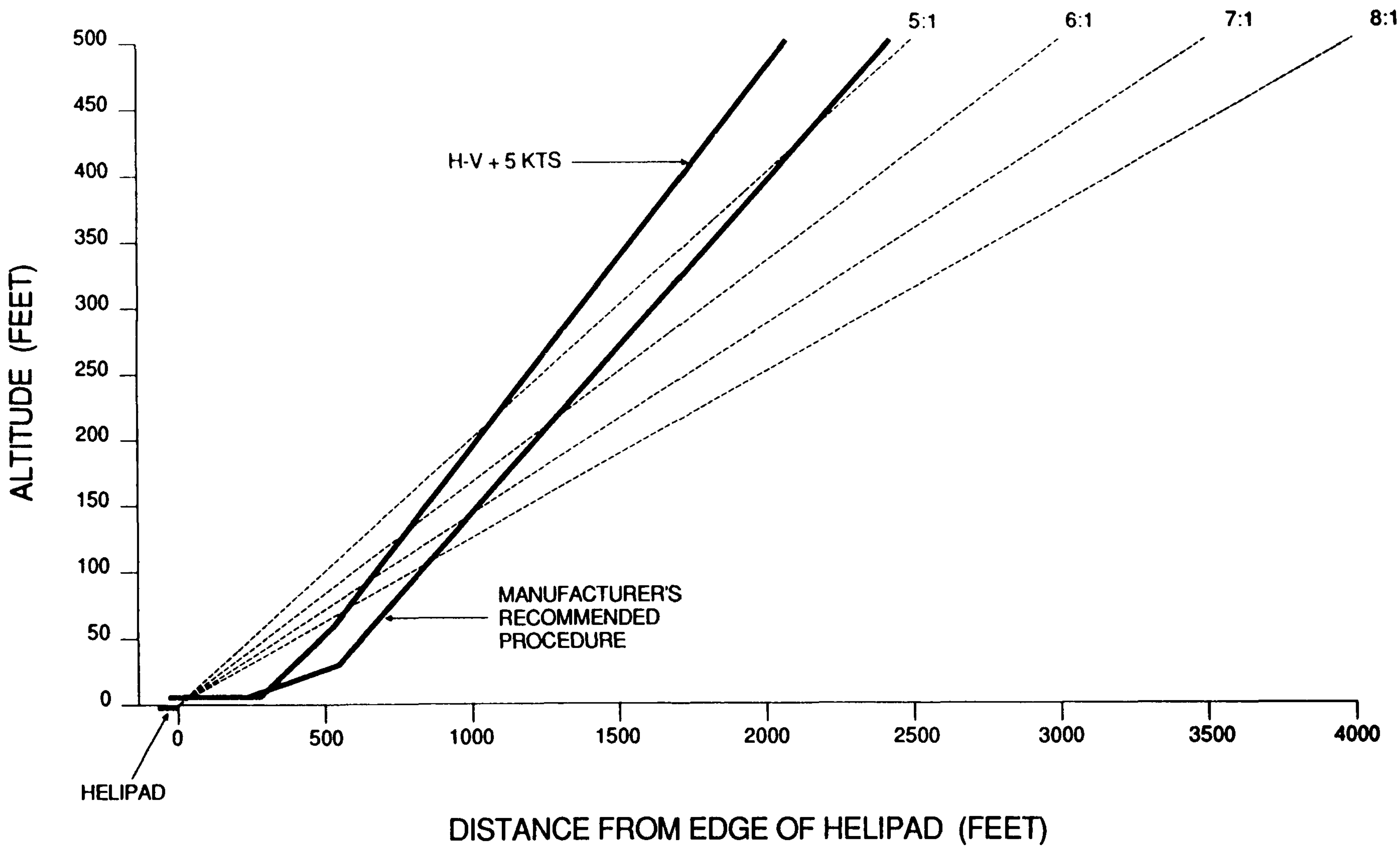
MBB BO 105 CBS DEPARTURE PROFILES

85% MAX. G.W., SEA LEVEL, STANDARD DAY



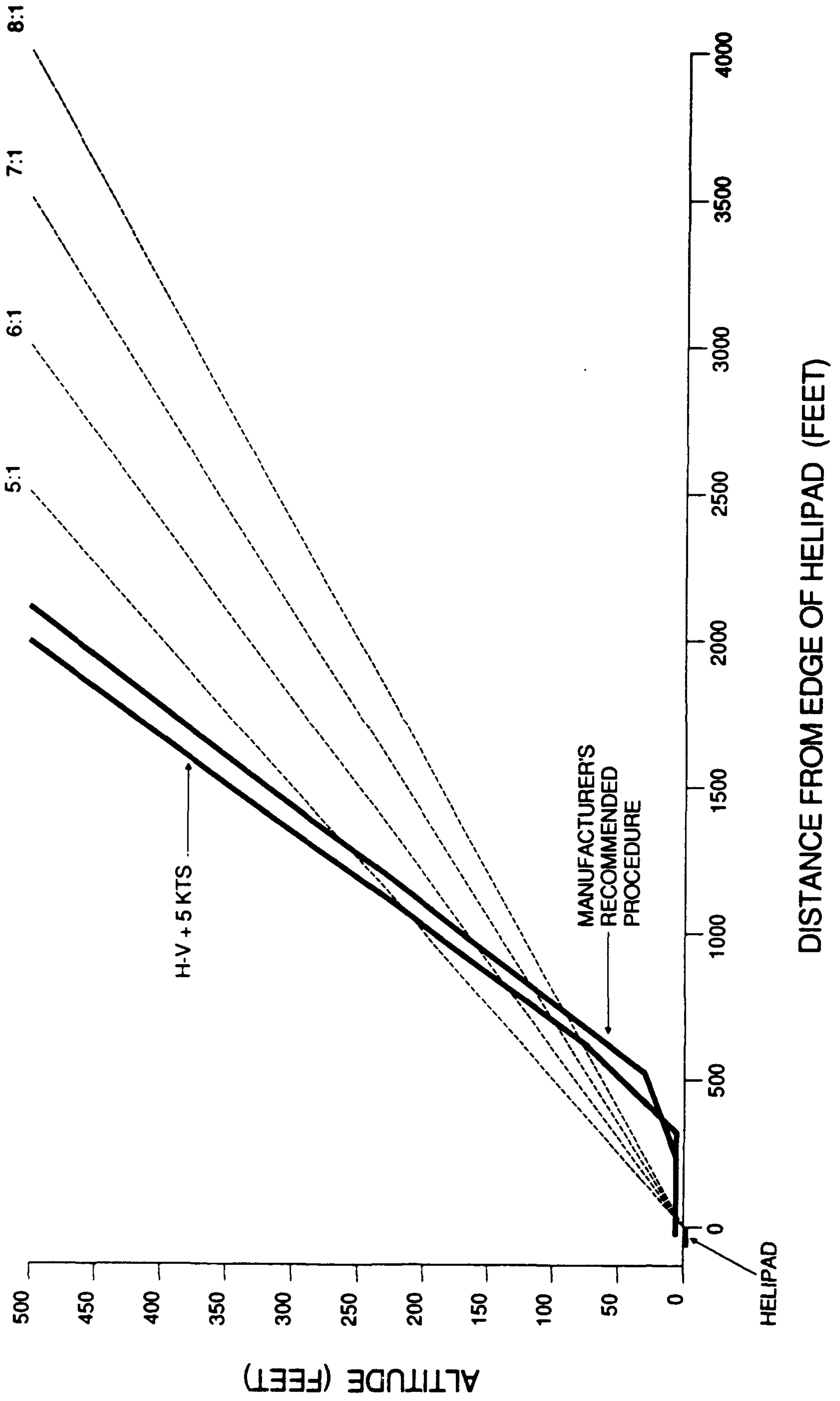
MBB BO 105 CBS DEPARTURE PROFILES

85% MAX. G.W., SEA LEVEL, HOT DAY



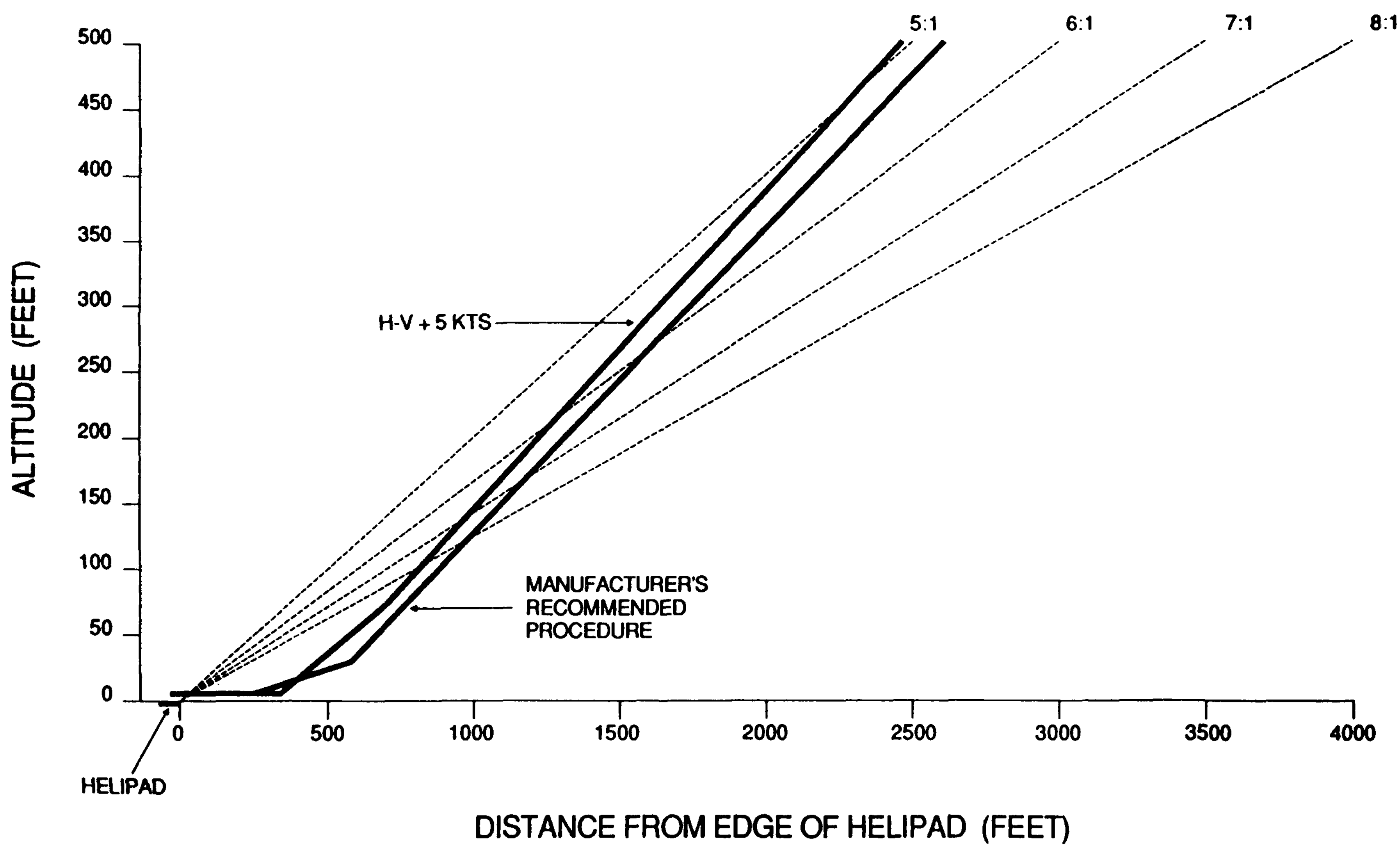
MBB BO 105 CBS DEPARTURE PROFILES

85% MAX. G.W., 2000 FEET, STANDARD DAY



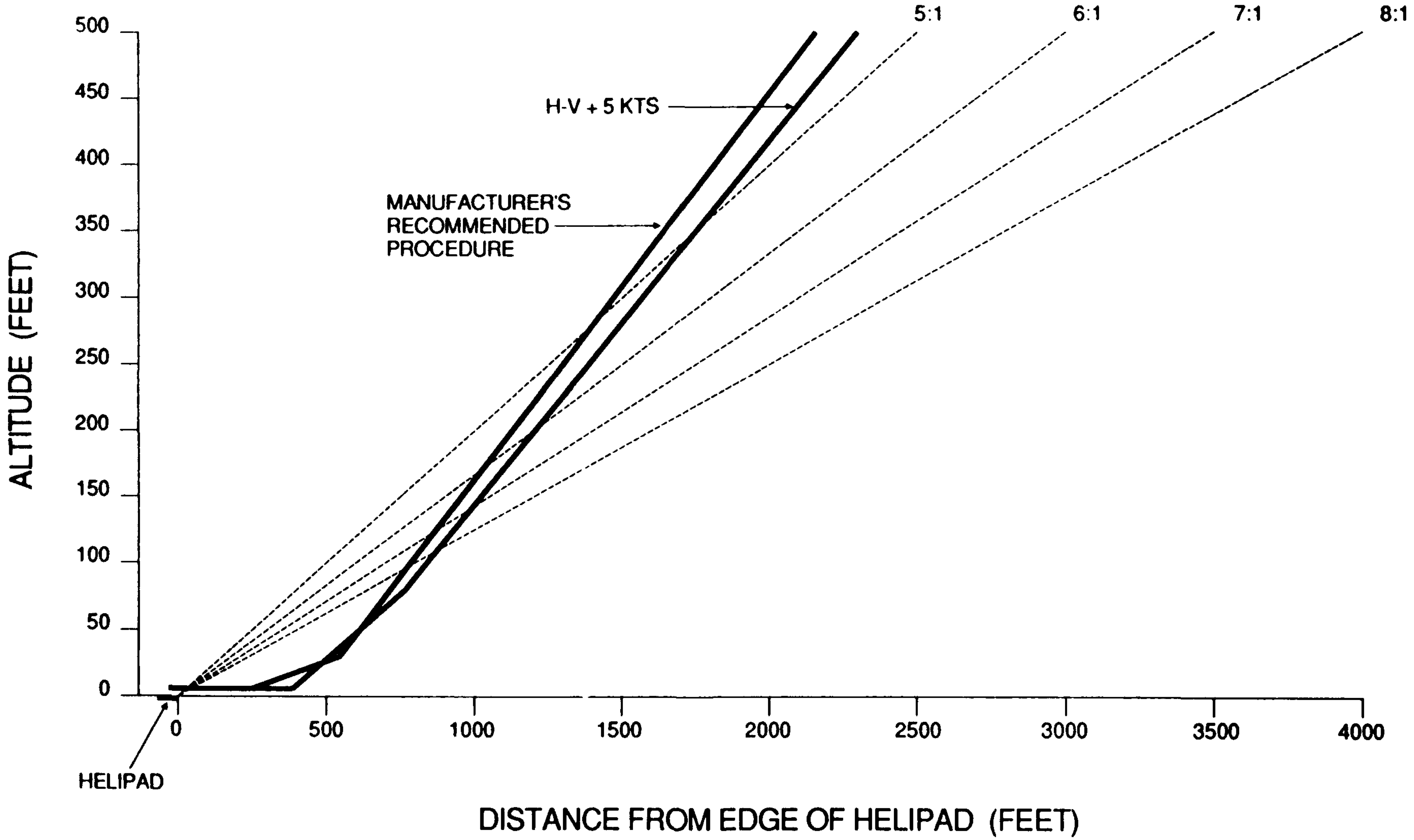
MBB BO 105 CBS DEPARTURE PROFILES

85% MAX. G.W., 2000 FEET, HOT DAY



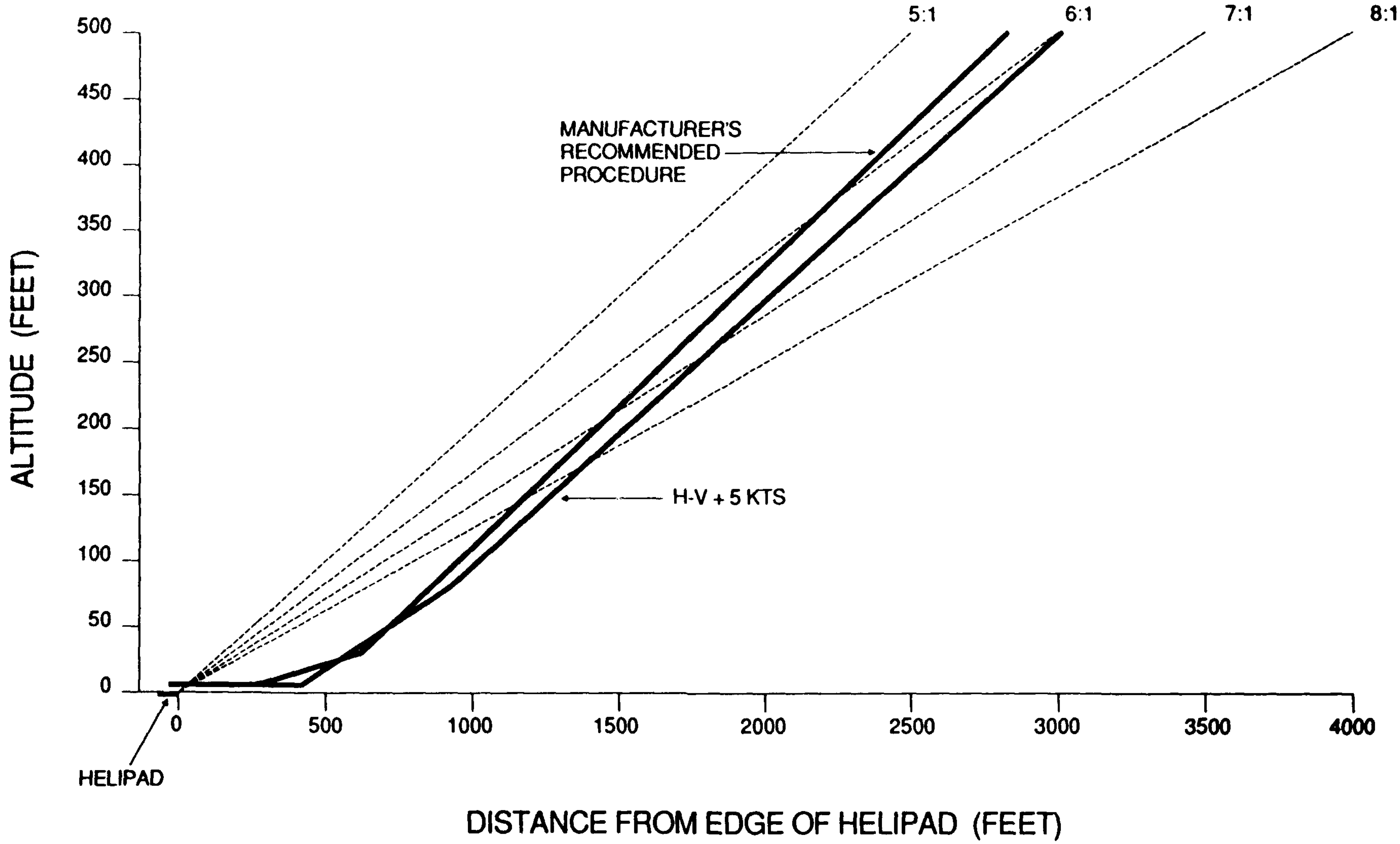
MBB BO 105 CBS DEPARTURE PROFILES

85% MAX. G.W., 4000 FEET, STANDARD DAY



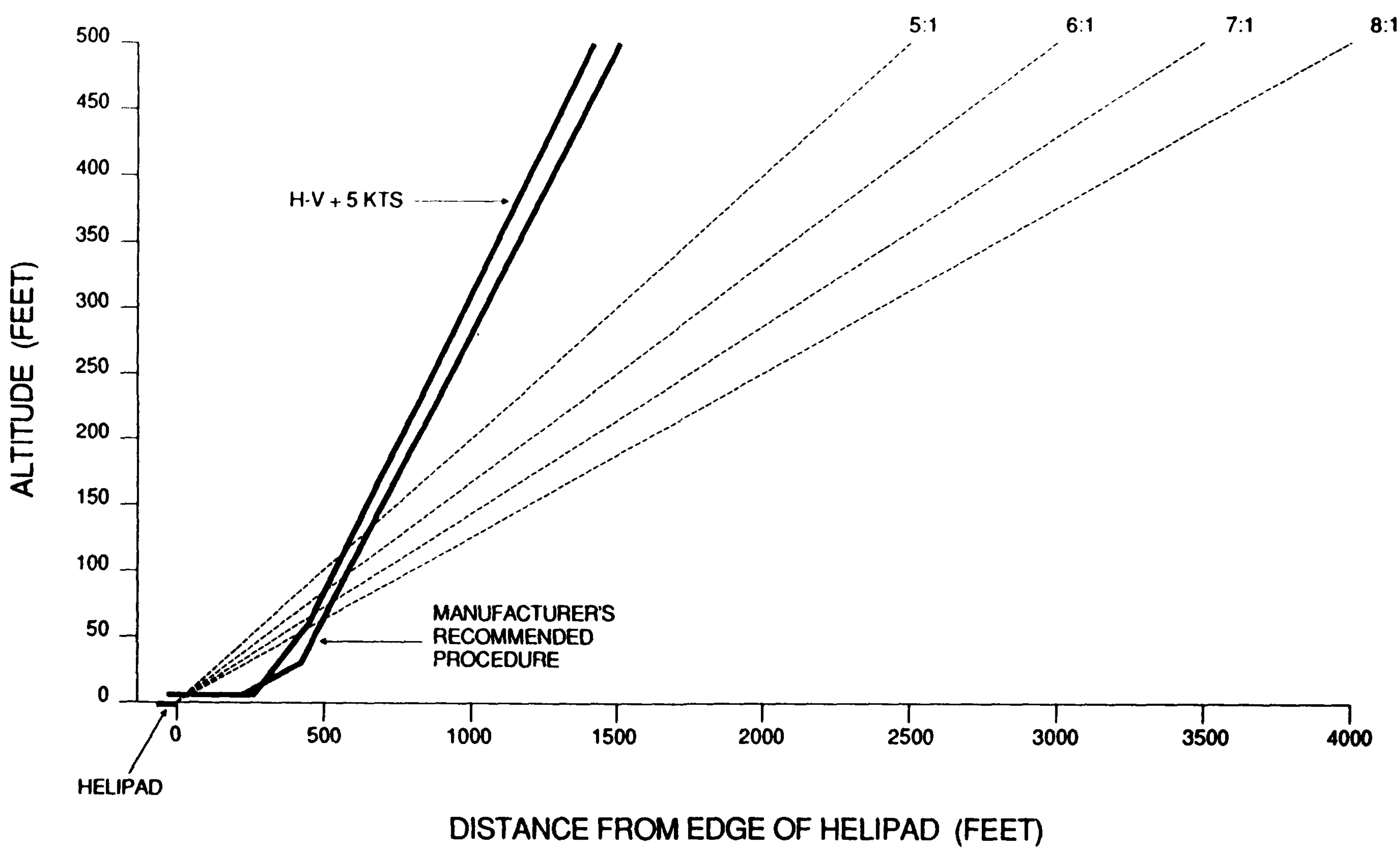
MBB BO 105 CBS DEPARTURE PROFILES

85% MAX. G.W., 4000 FEET, HOT DAY



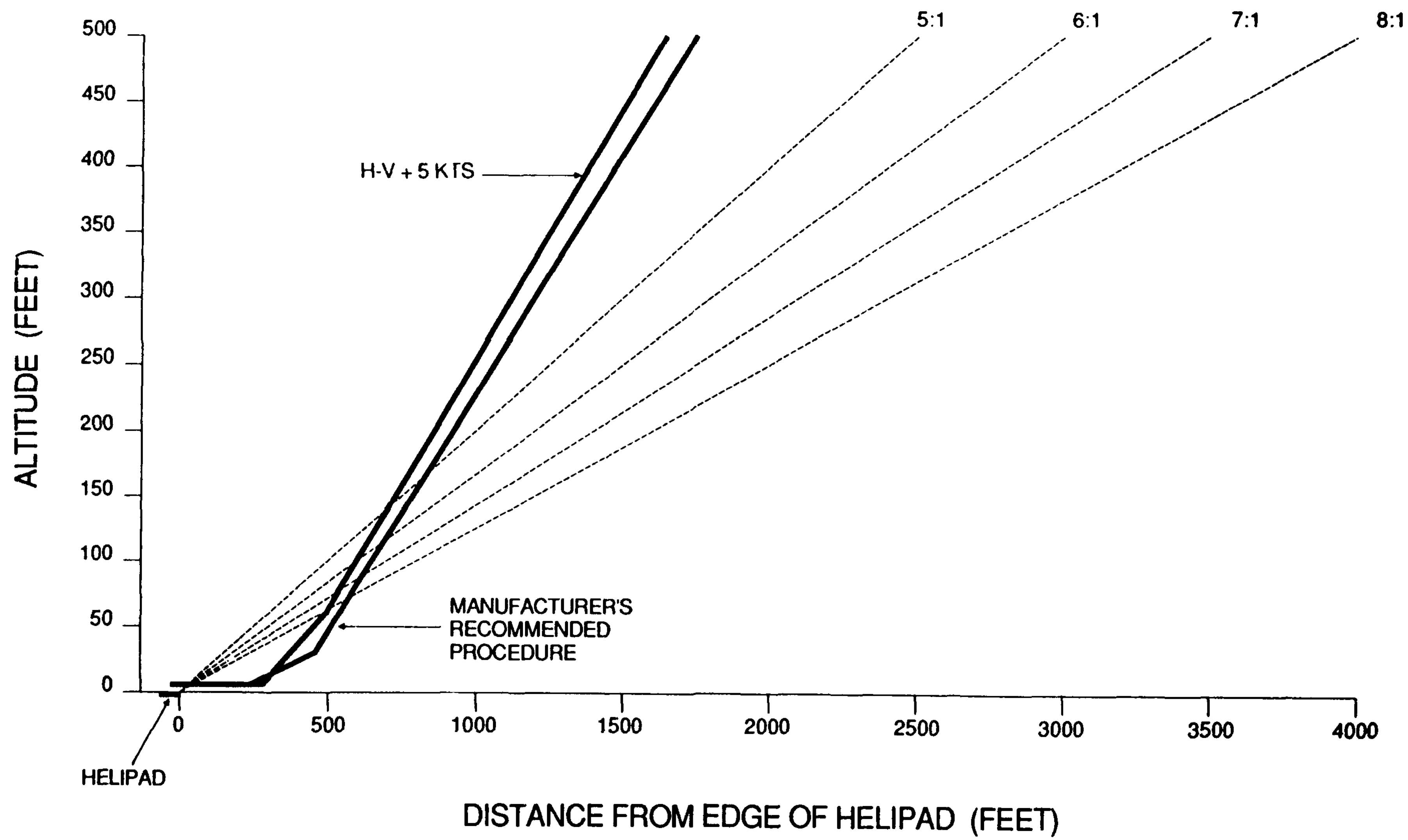
MBB BO 105 CBS DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL, STANDARD DAY



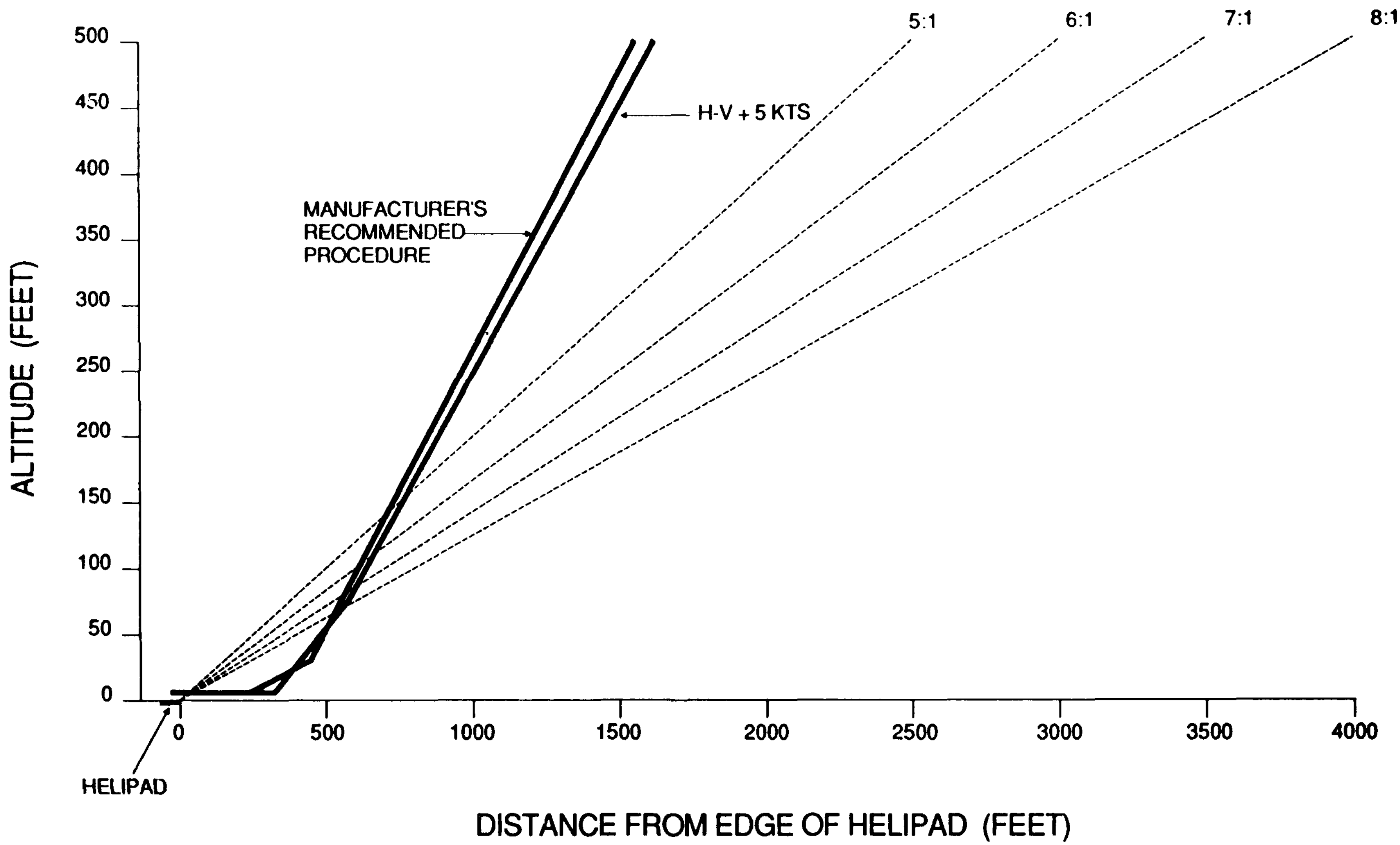
MBB BO 105 CBS DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL, HOT DAY



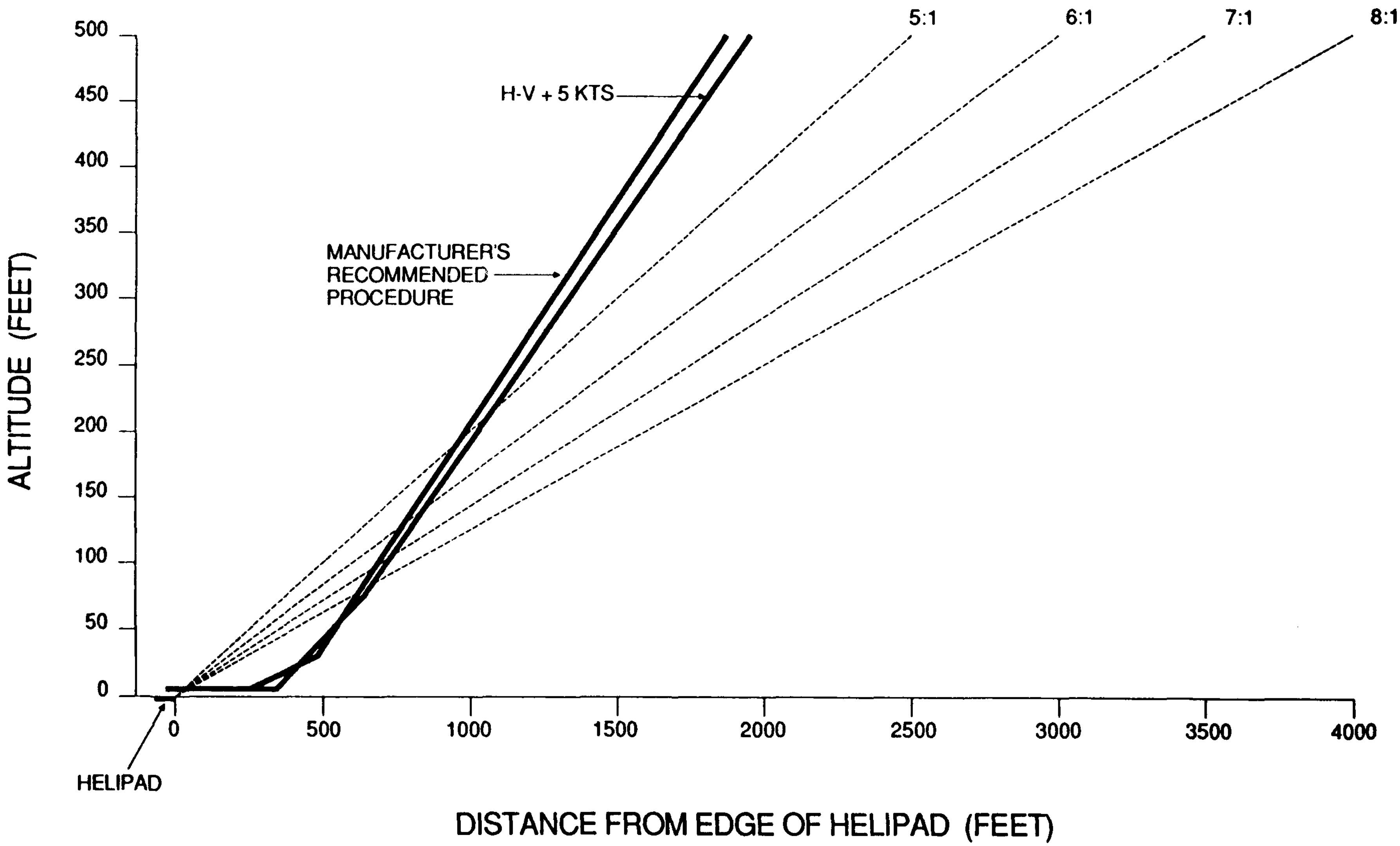
MBB BO 105 CBS DEPARTURE PROFILES

70% MAX. G.W., 2000 FEET, STANDARD DAY



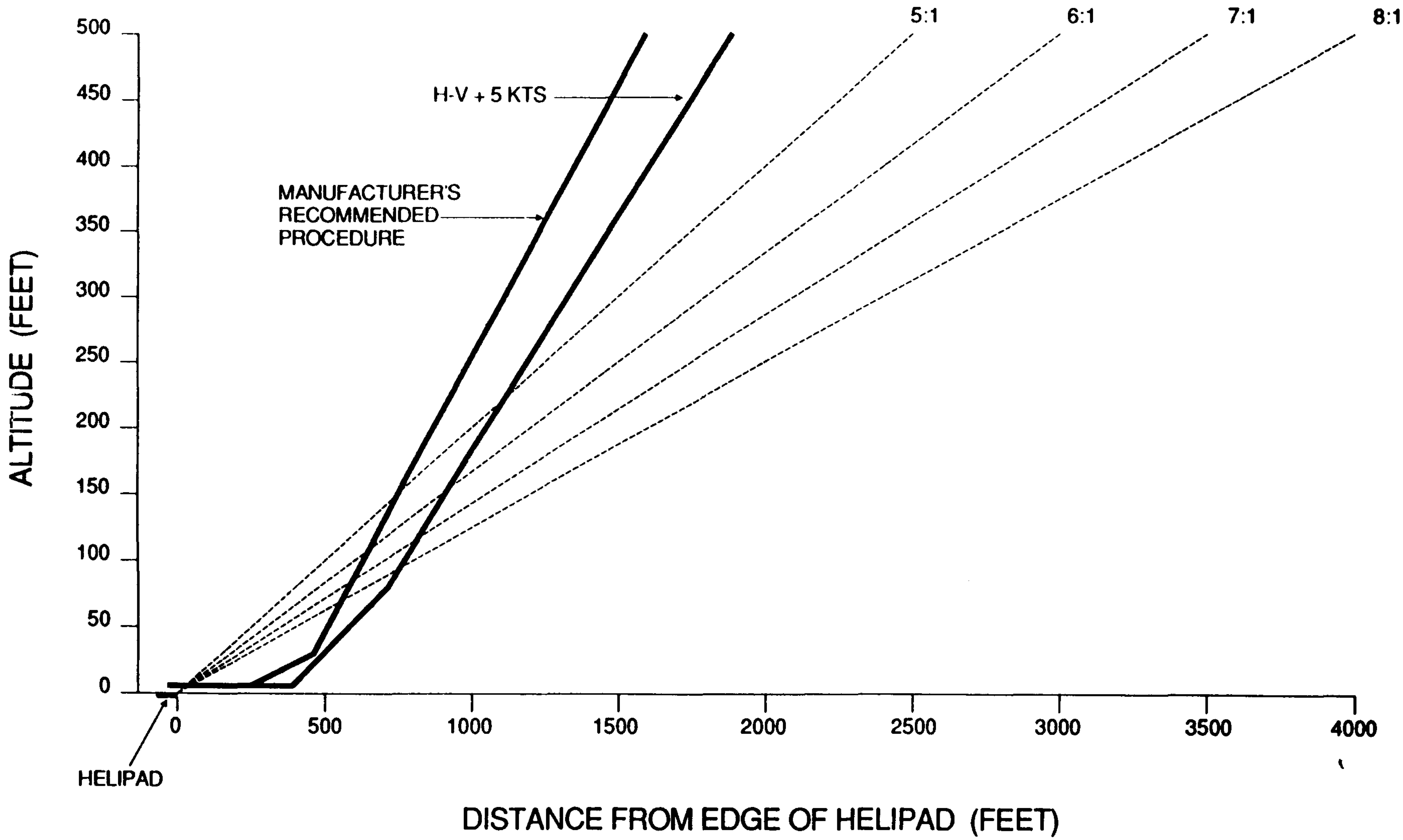
MBB BO 105 CBS DEPARTURE PROFILES

70% MAX. G.W., 2000 FEET, HOT DAY



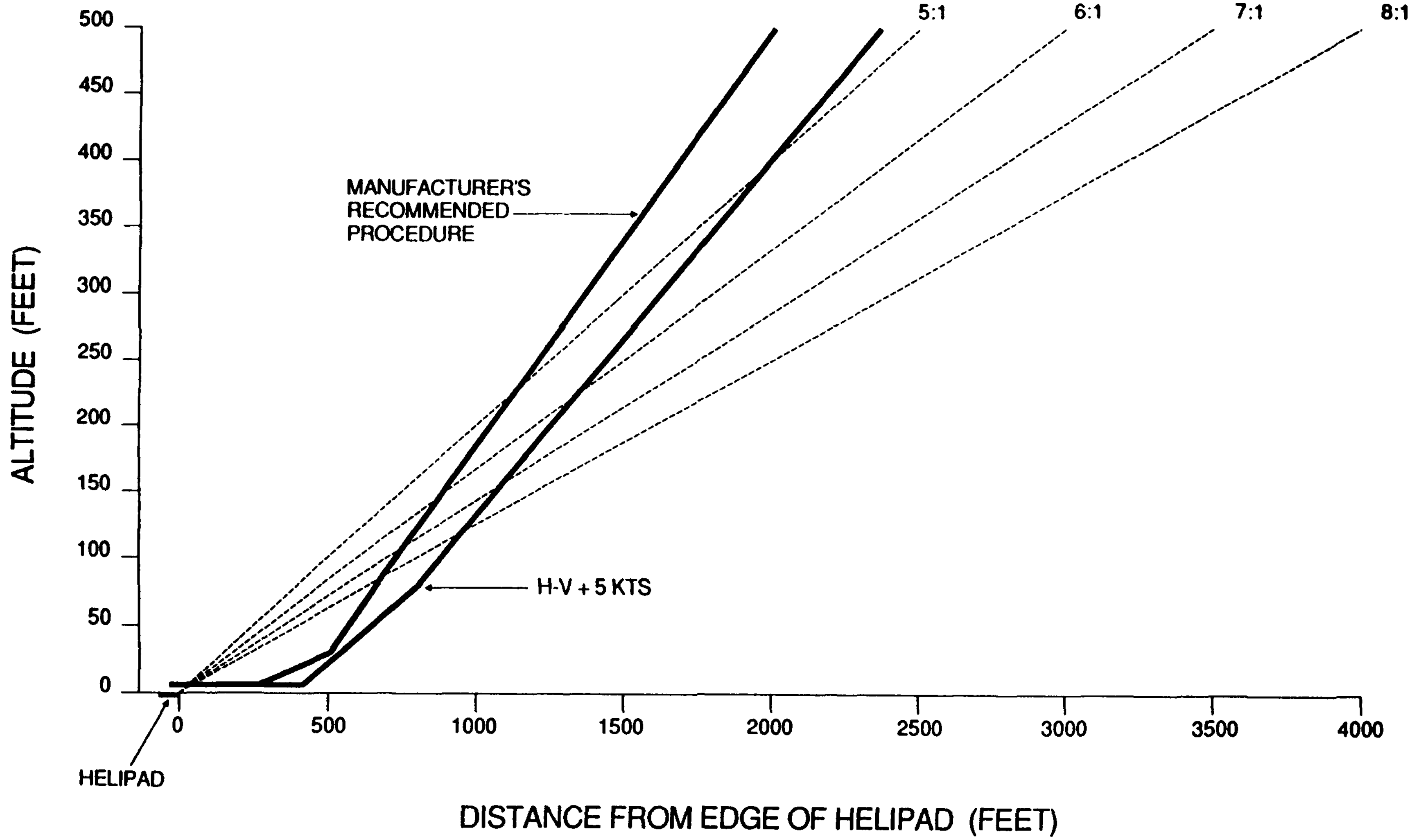
MBB BO 105 CBS DEPARTURE PROFILES

70% MAX. G.W., 4000 FEET, STANDARD DAY



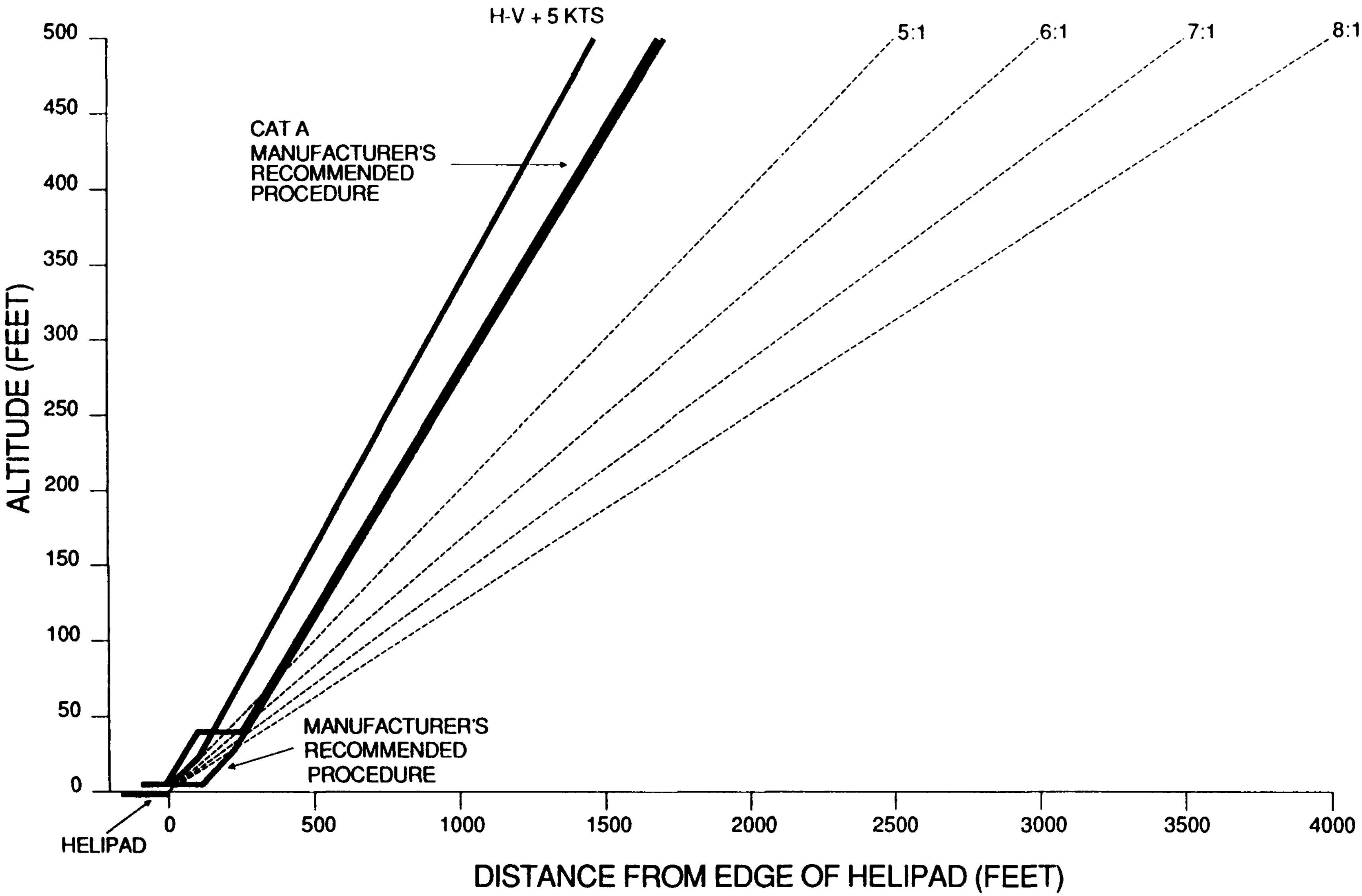
MBB BO 105 CBS DEPARTURE PROFILES

70% MAX. G.W., 4000 FEET, HOT DAY



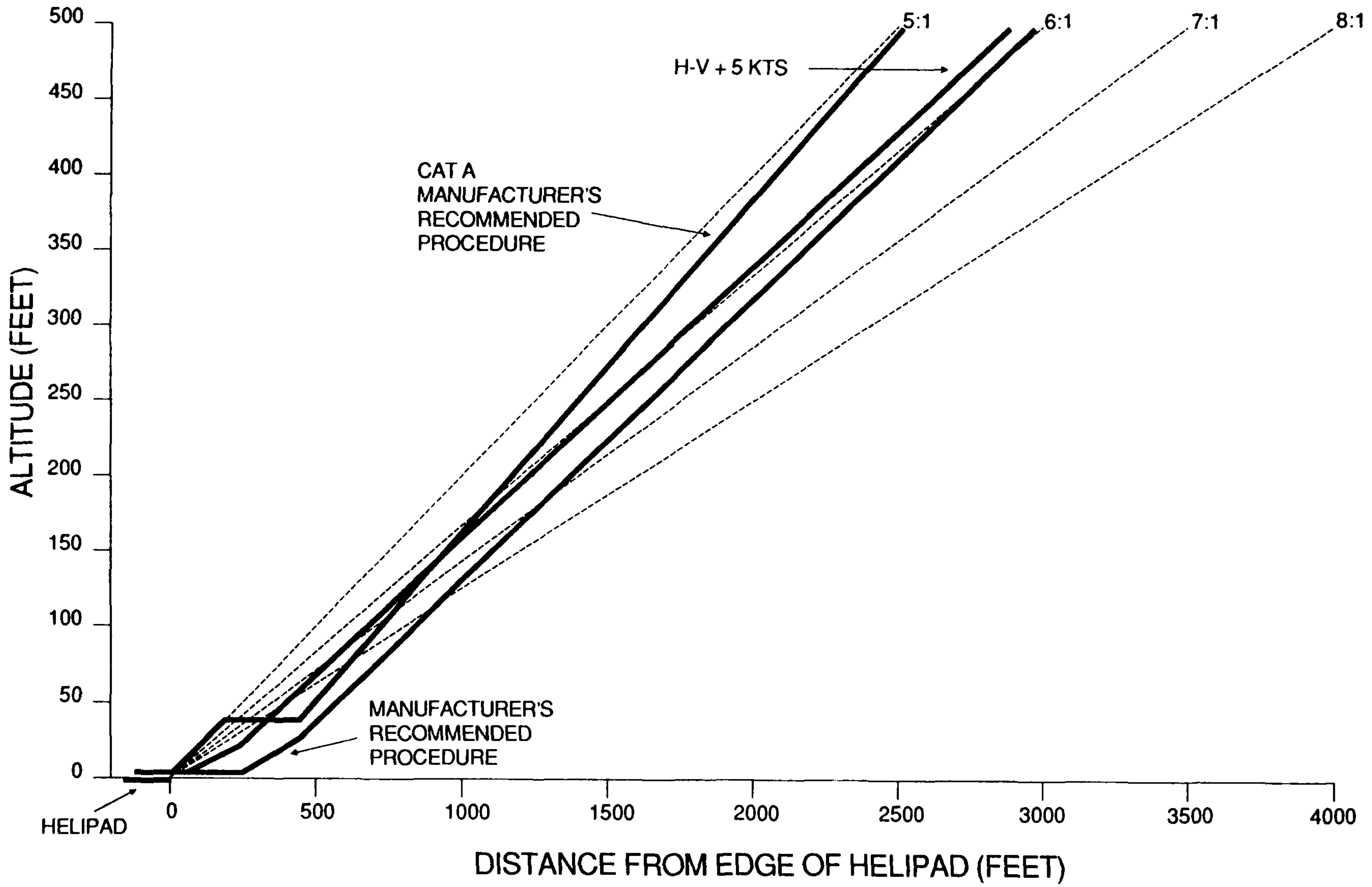
S 76A DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, STANDARD DAY



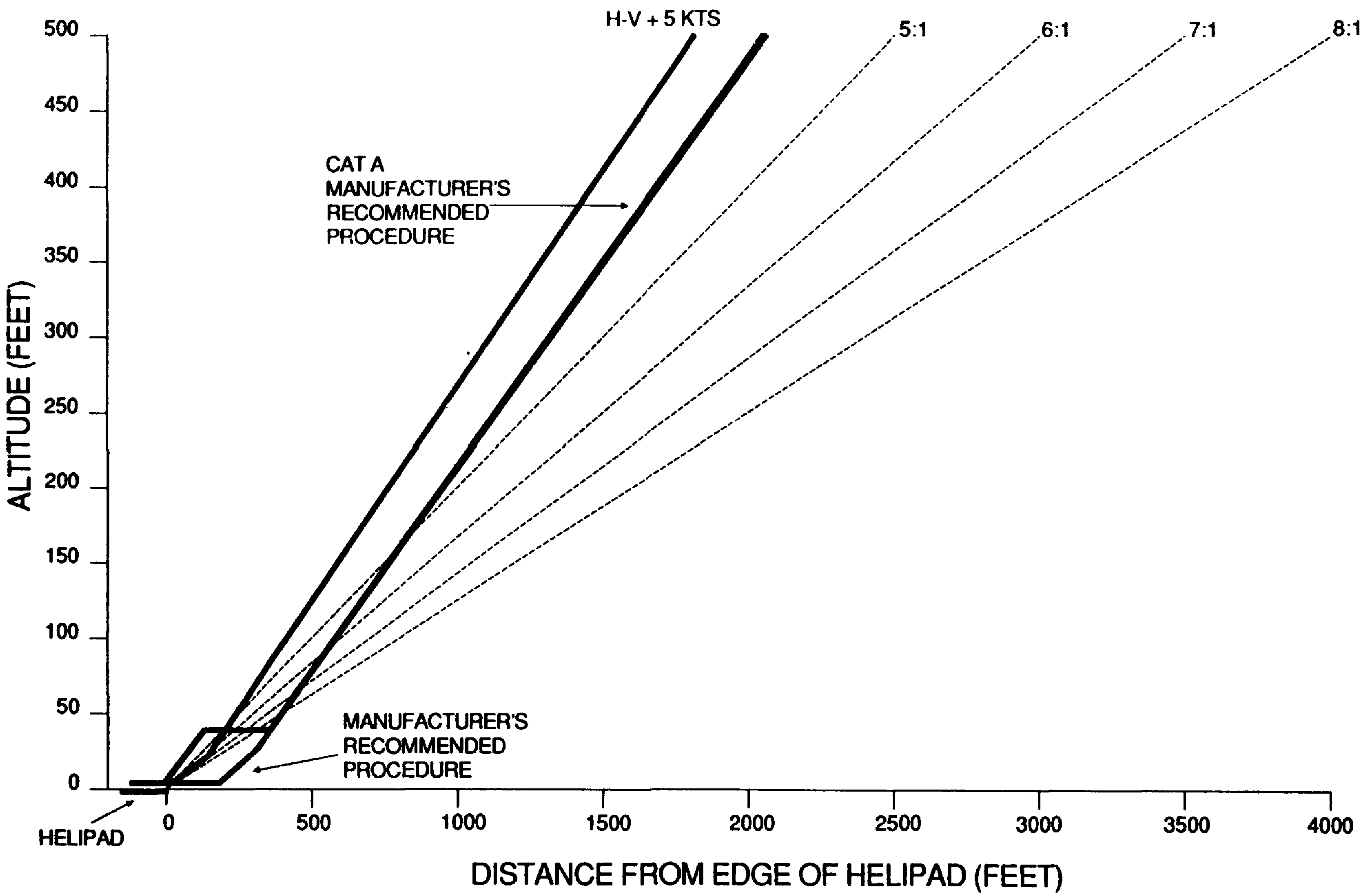
S 76A DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, HOT DAY



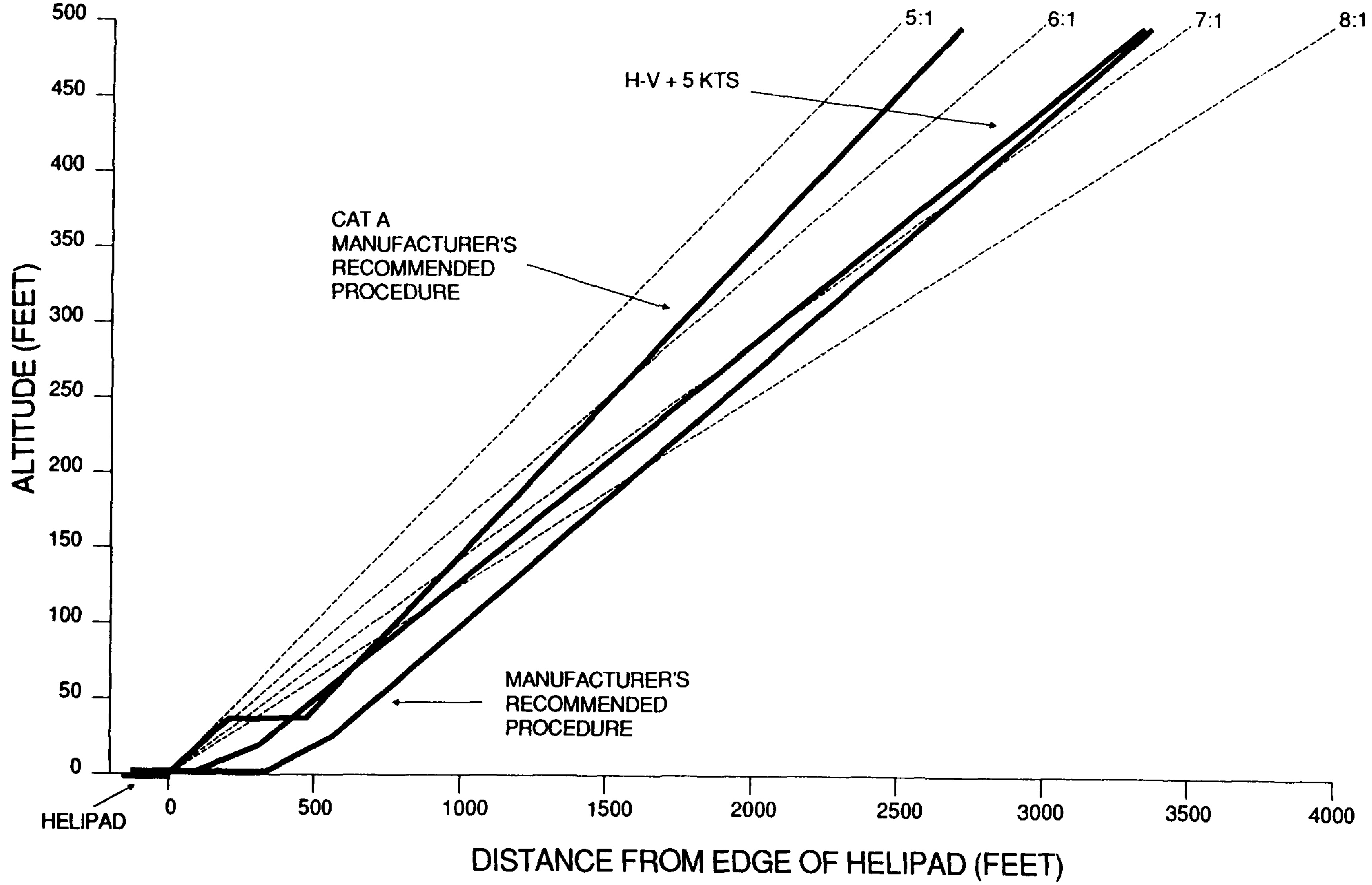
S 76A DEPARTURE PROFILES

MAX. G.W., 2000 FEET, STANDARD DAY



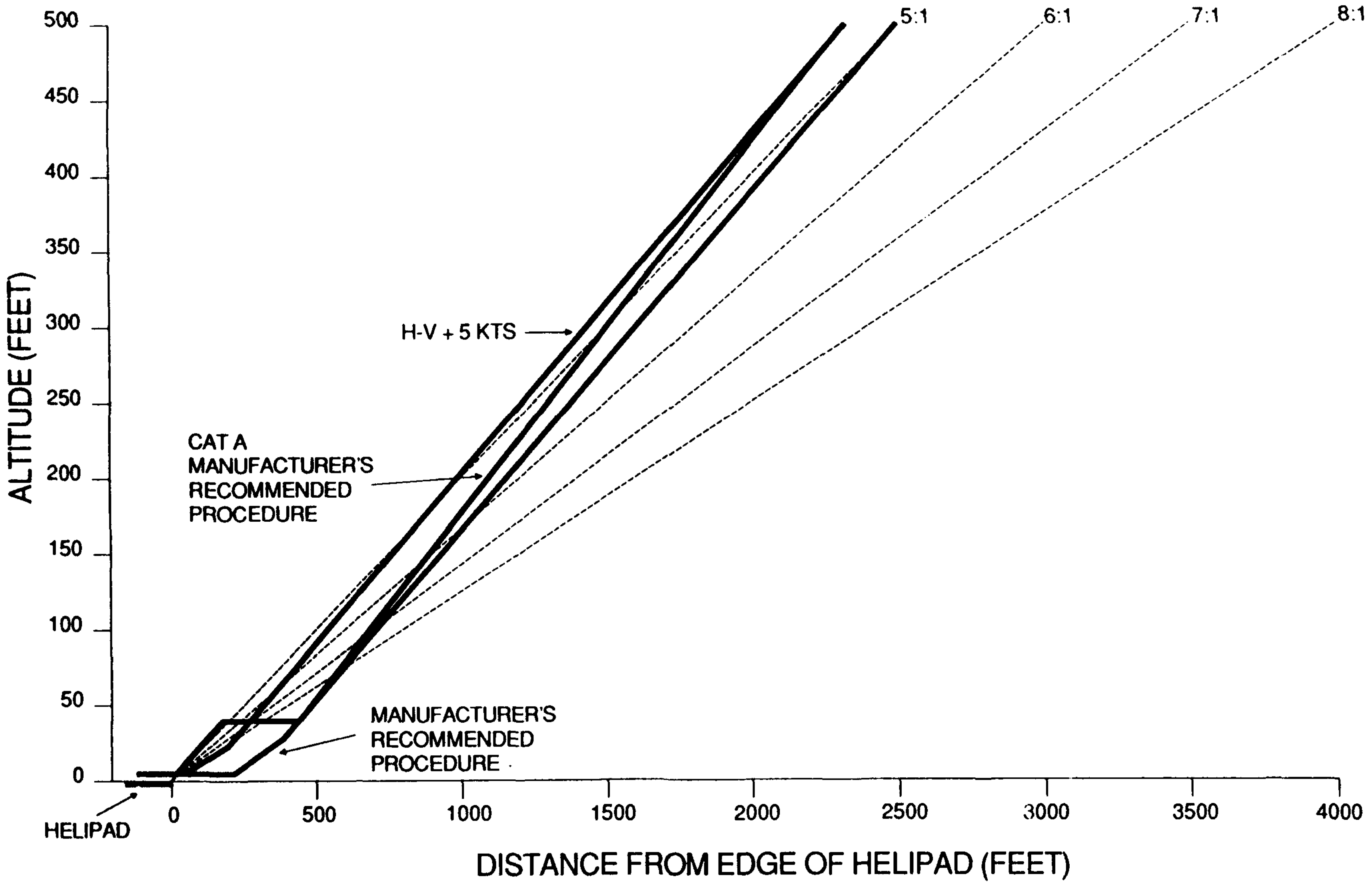
S 76A DEPARTURE PROFILES

MAX. G.W., 2000 FEET, HOT DAY



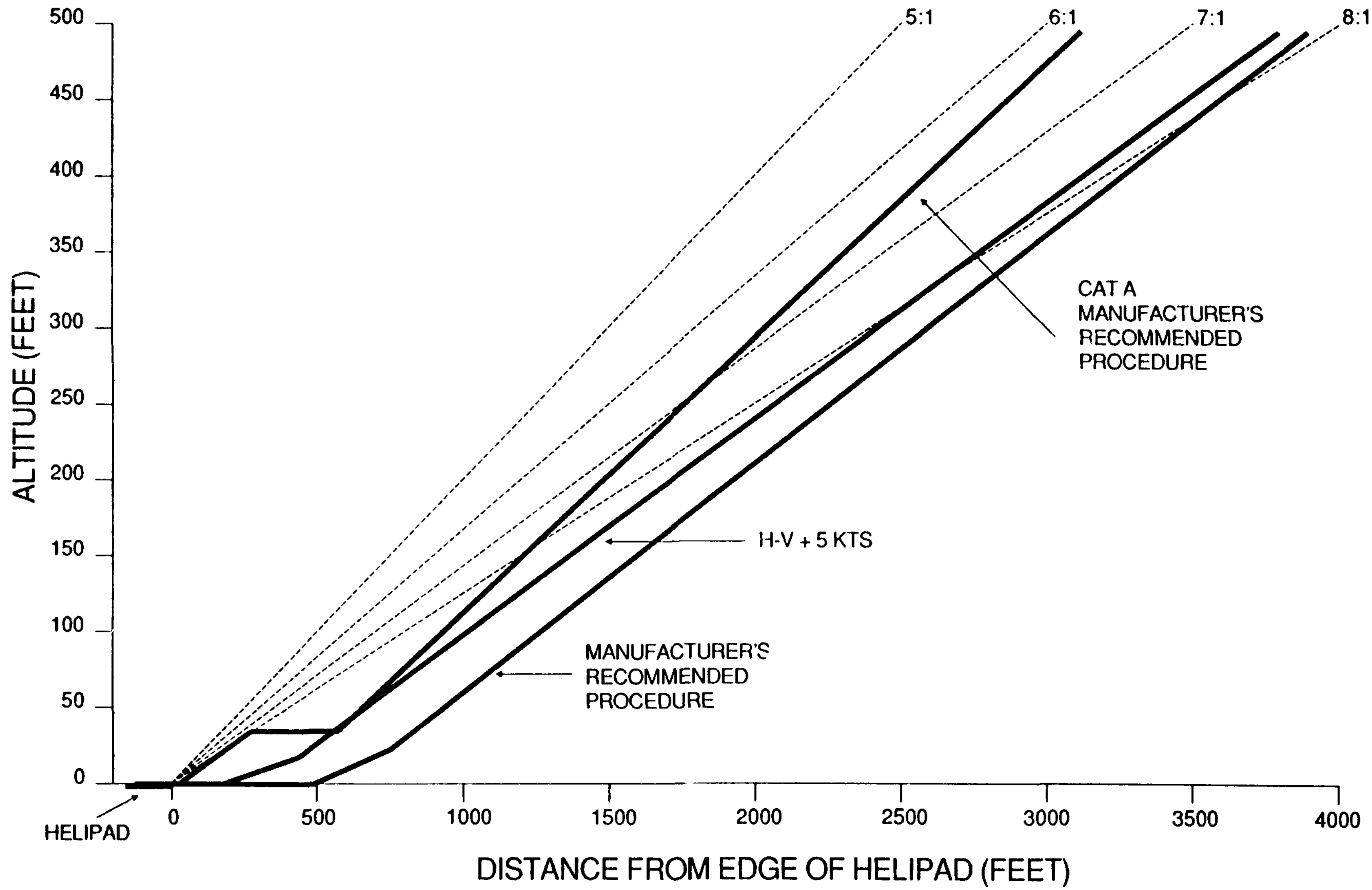
S 76A DEPARTURE PROFILES

MAX. G.W., 4000 FEET, STANDARD DAY



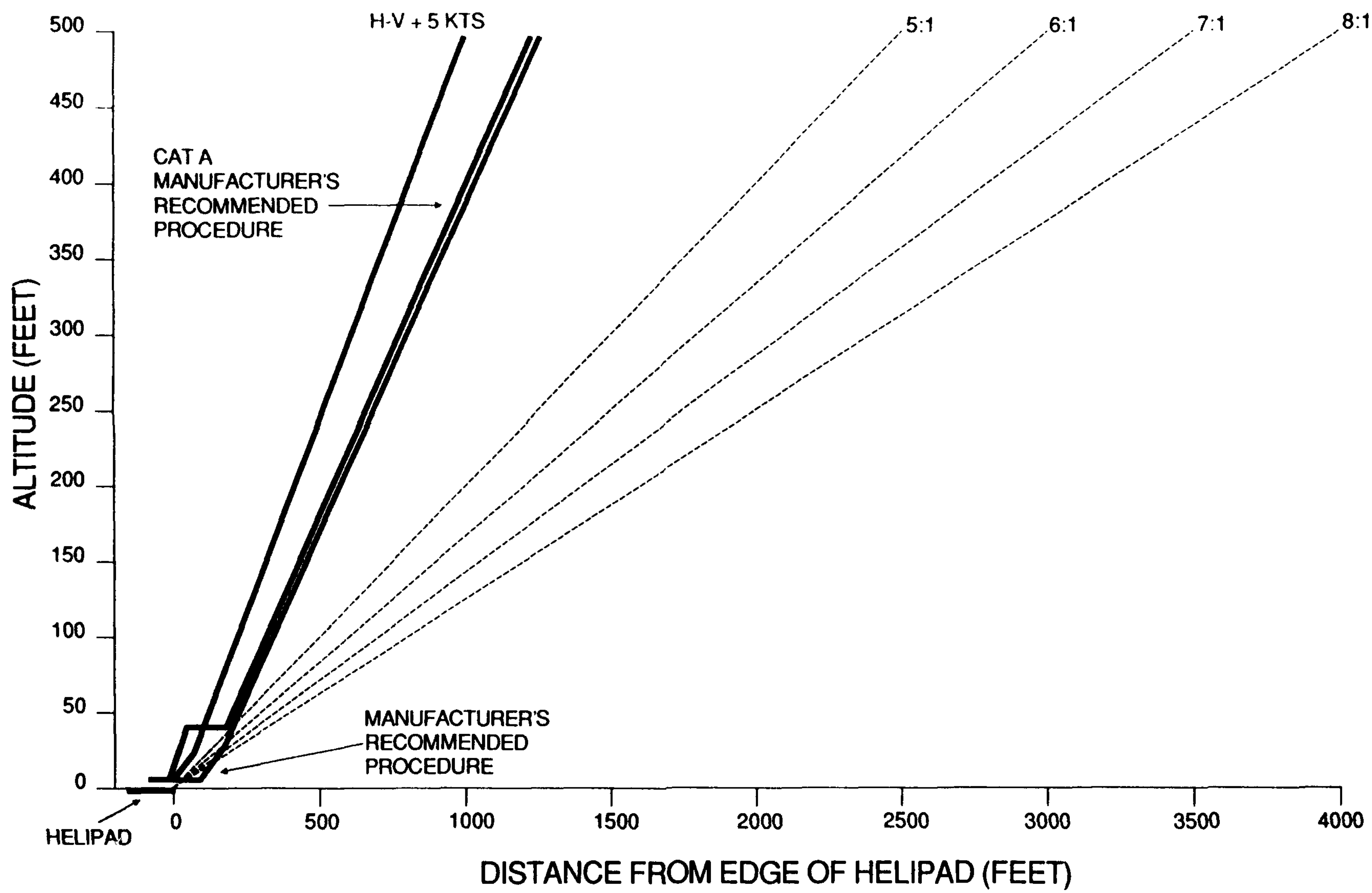
S 76A DEPARTURE PROFILES

MAX. G.W., 4000 FEET, HOT DAY



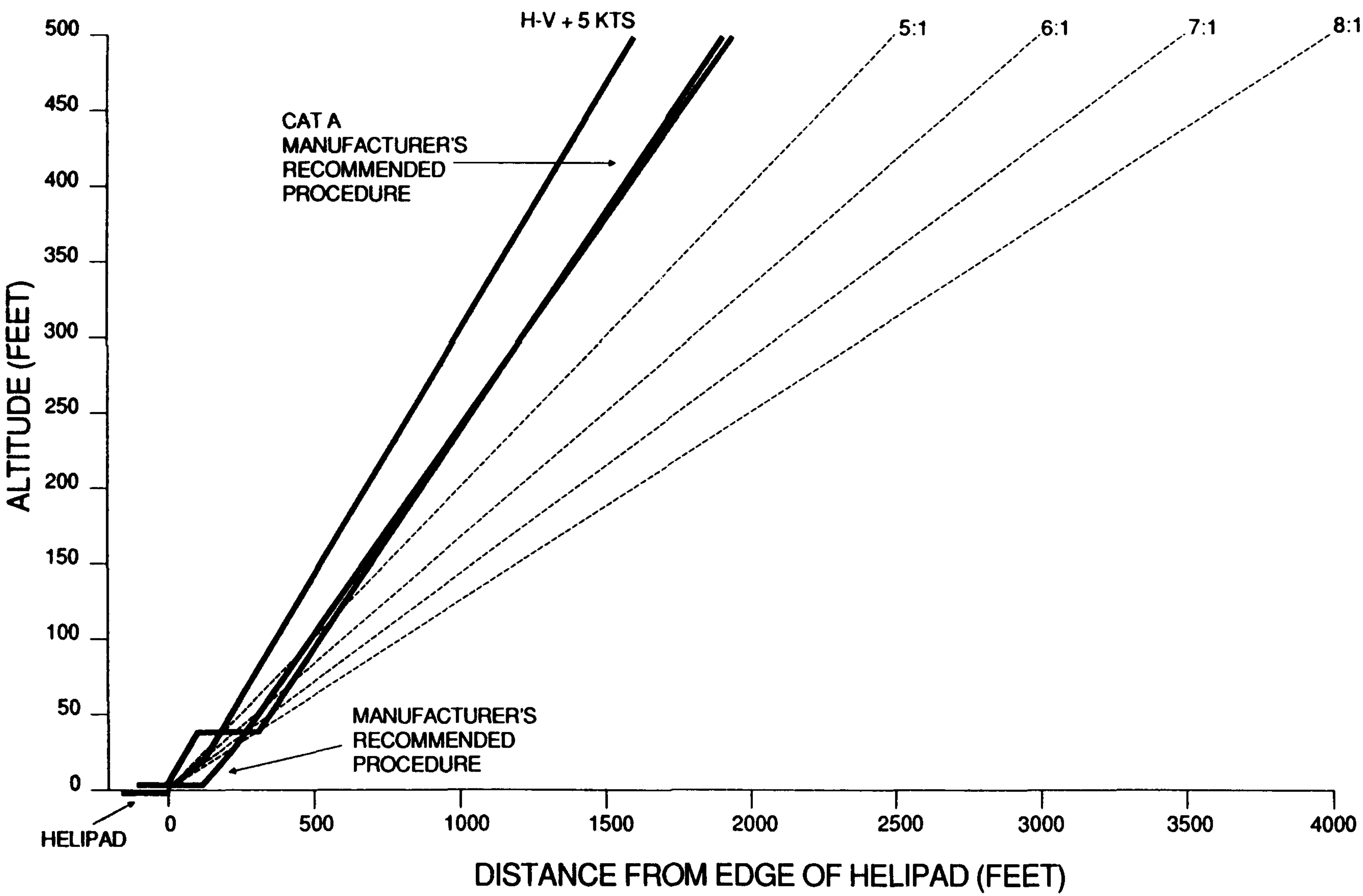
S 76A DEPARTURE PROFILES

85% MAX. G.W., SEA LEVEL, STANDARD DAY



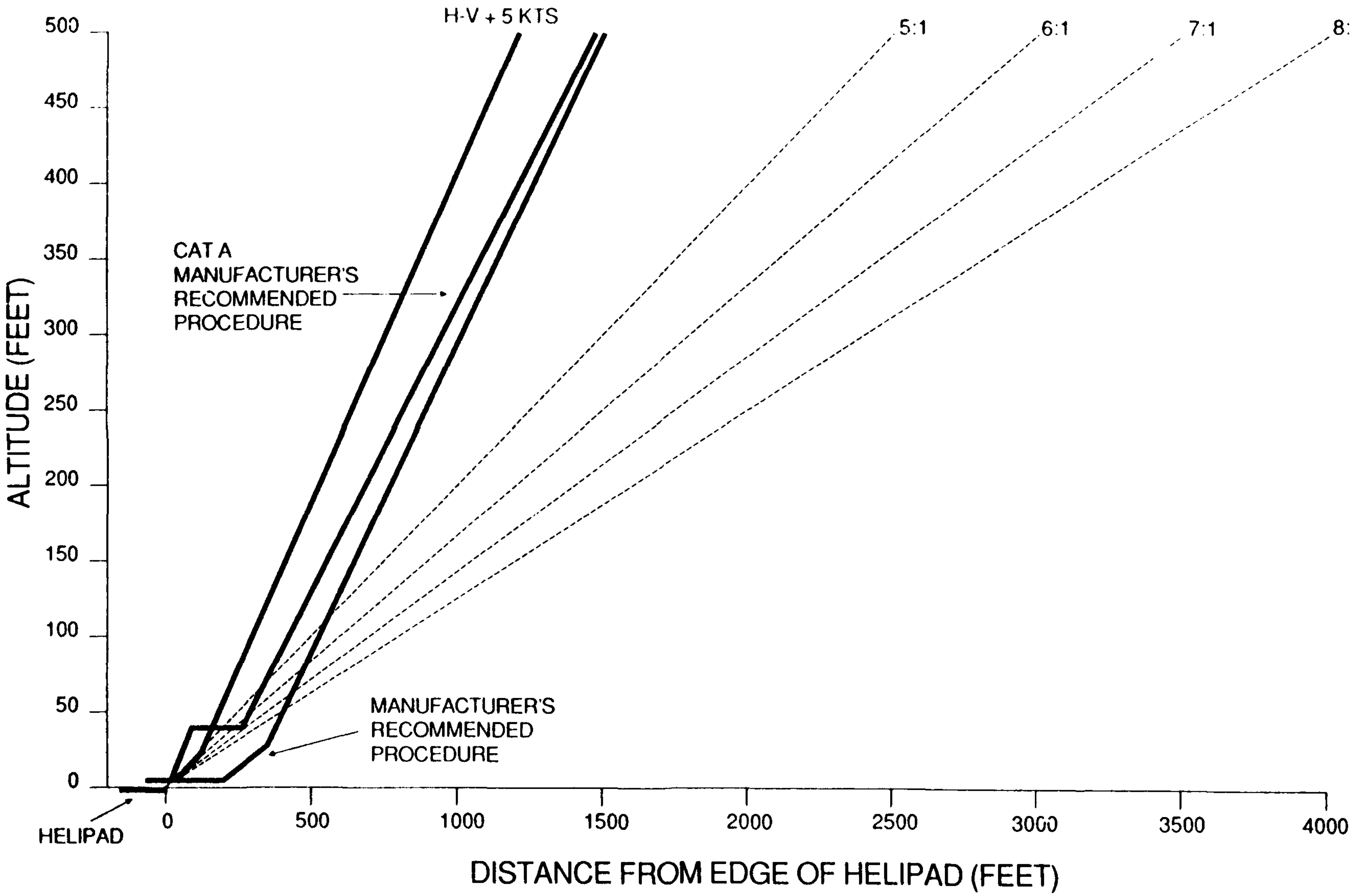
S 76A DEPARTURE PROFILES

85% MAX. G.W., SEA LEVEL, HOT DAY



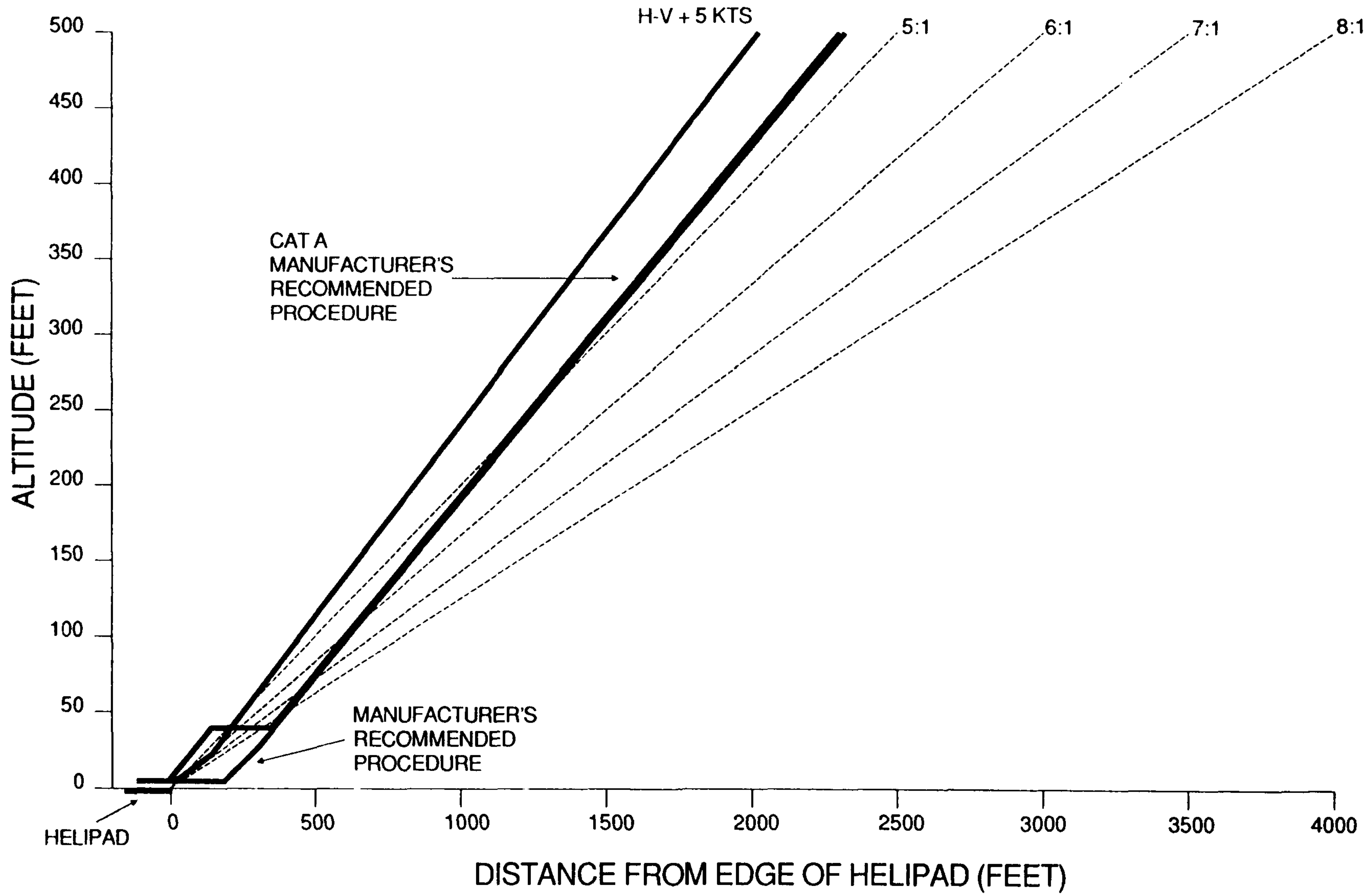
S 76A DEPARTURE PROFILES

85% MAX. G.W., 2000 FEET, STANDARD DAY



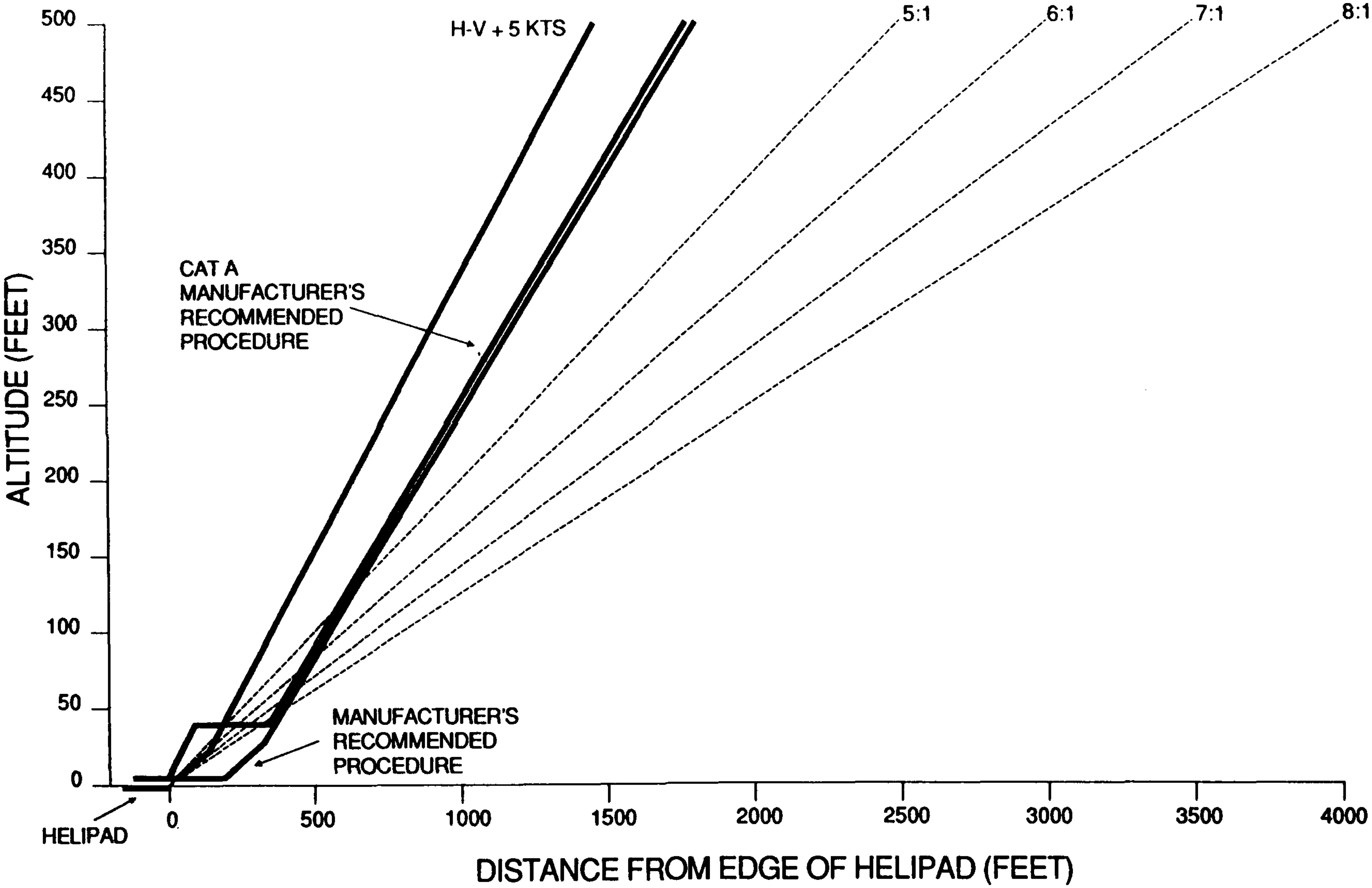
S 76A DEPARTURE PROFILES

85% MAX G.W., 2000 FEET, HOT DAY



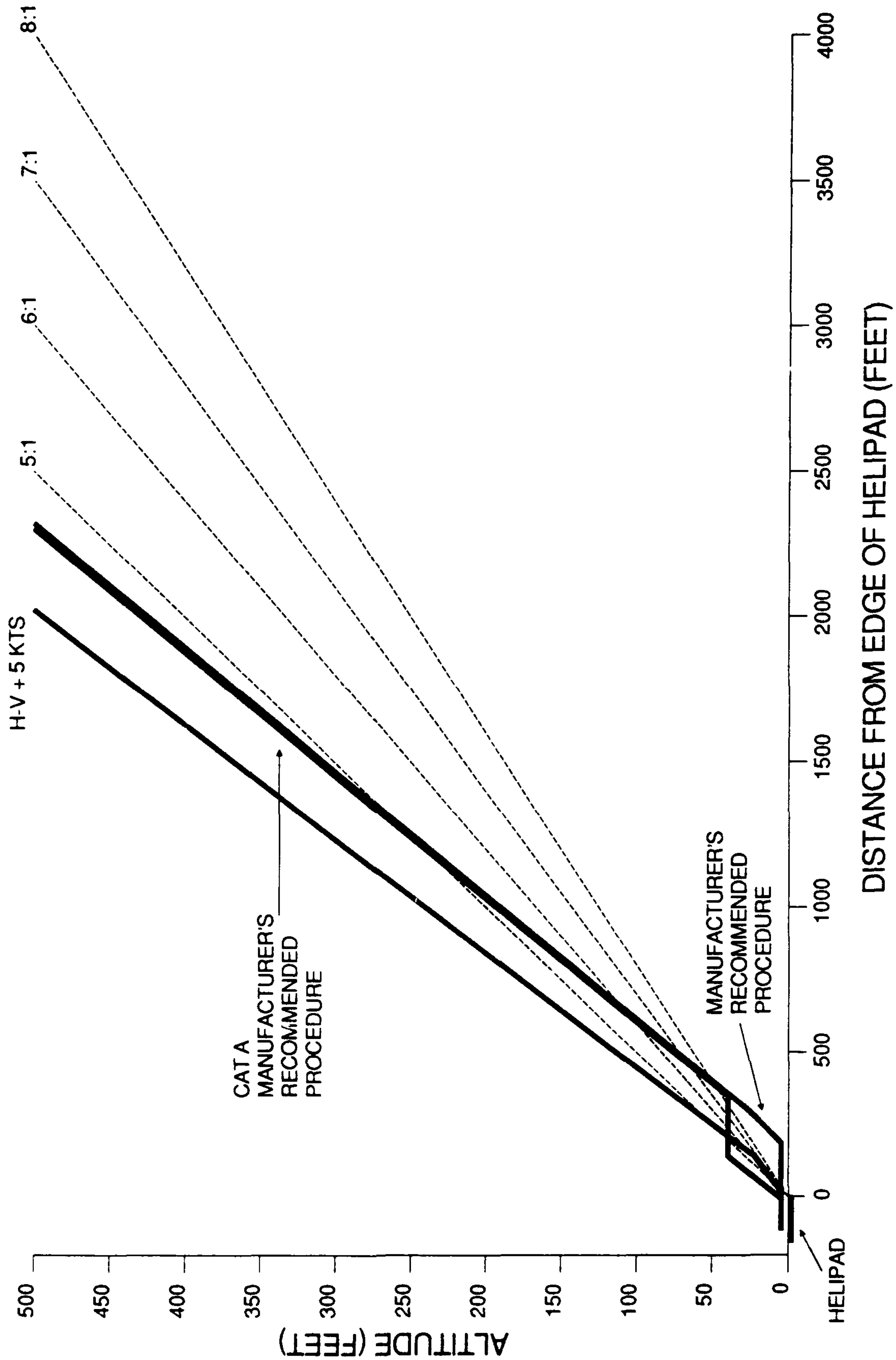
S 76A DEPARTURE PROFILES

85% MAX G.W., 4000 FEET, STANDARD DAY



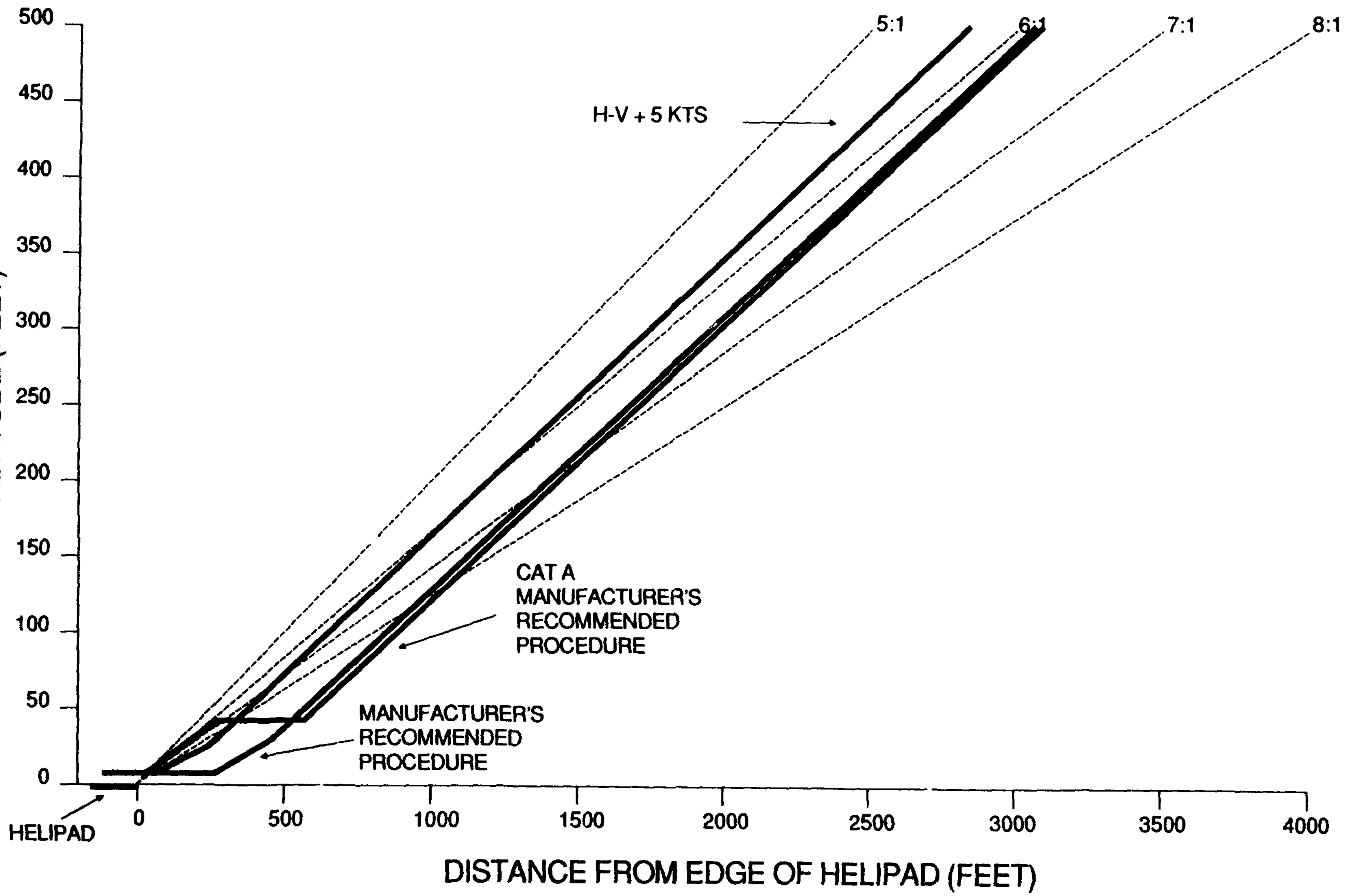
S 76A DEPARTURE PROFILES

85% MAX G.W., 2000 FEET, HOT DAY



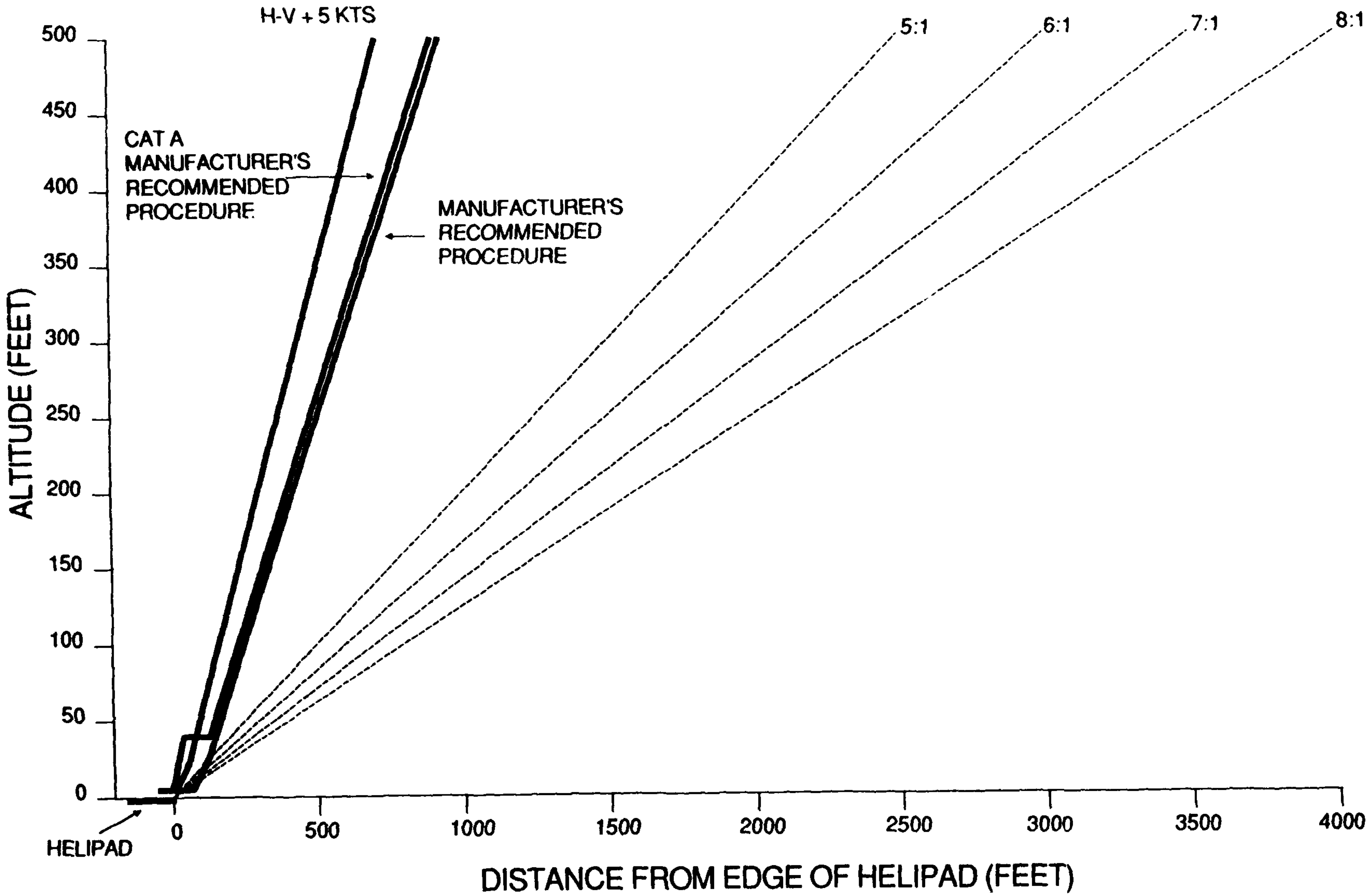
S 76A DEPARTURE PROFILES

85% MAX. G.W., 4000 FEET, HOT DAY



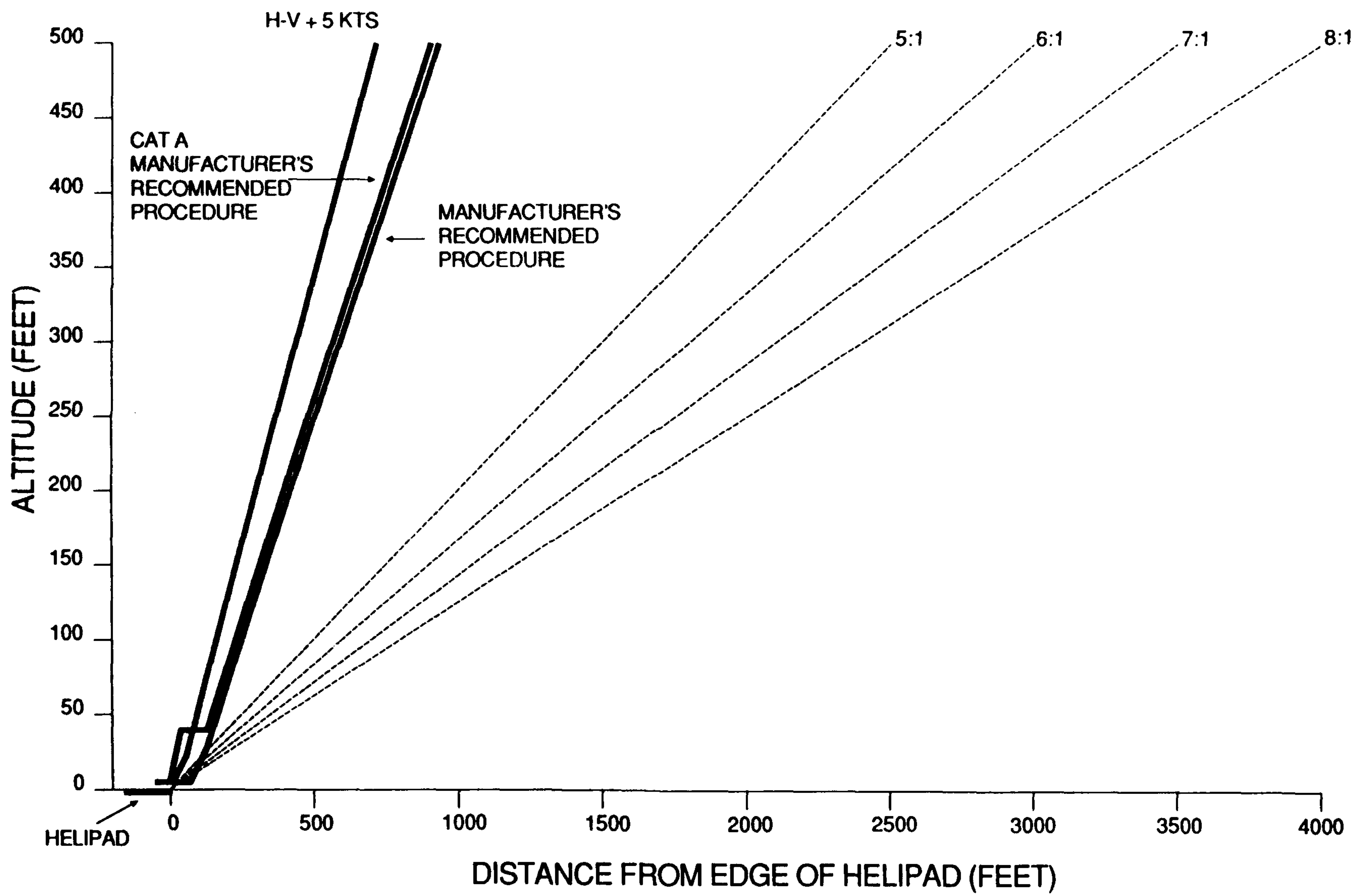
S 76A DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL, STANDARD DAY



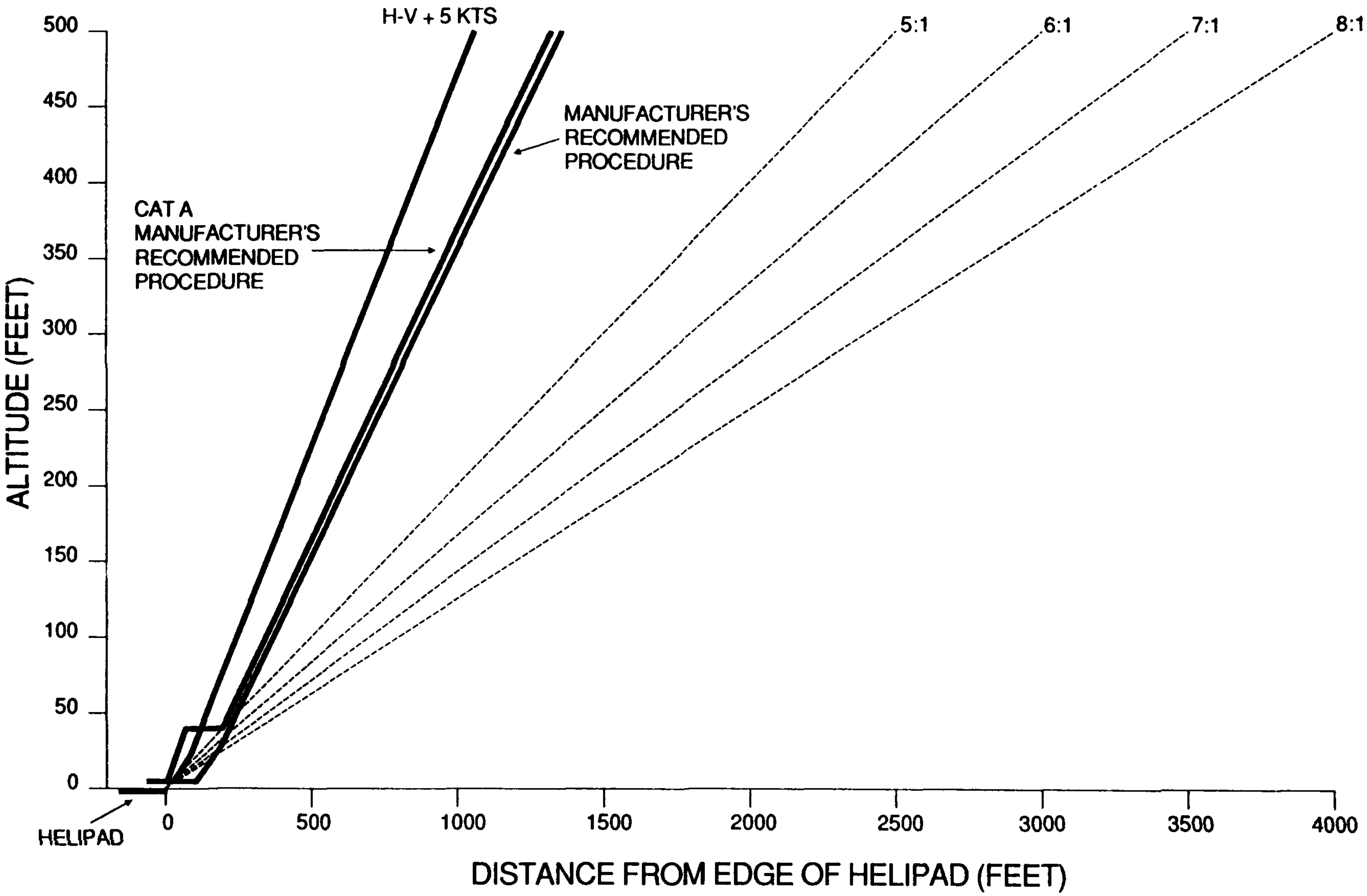
S 76A DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL, STANDARD DAY



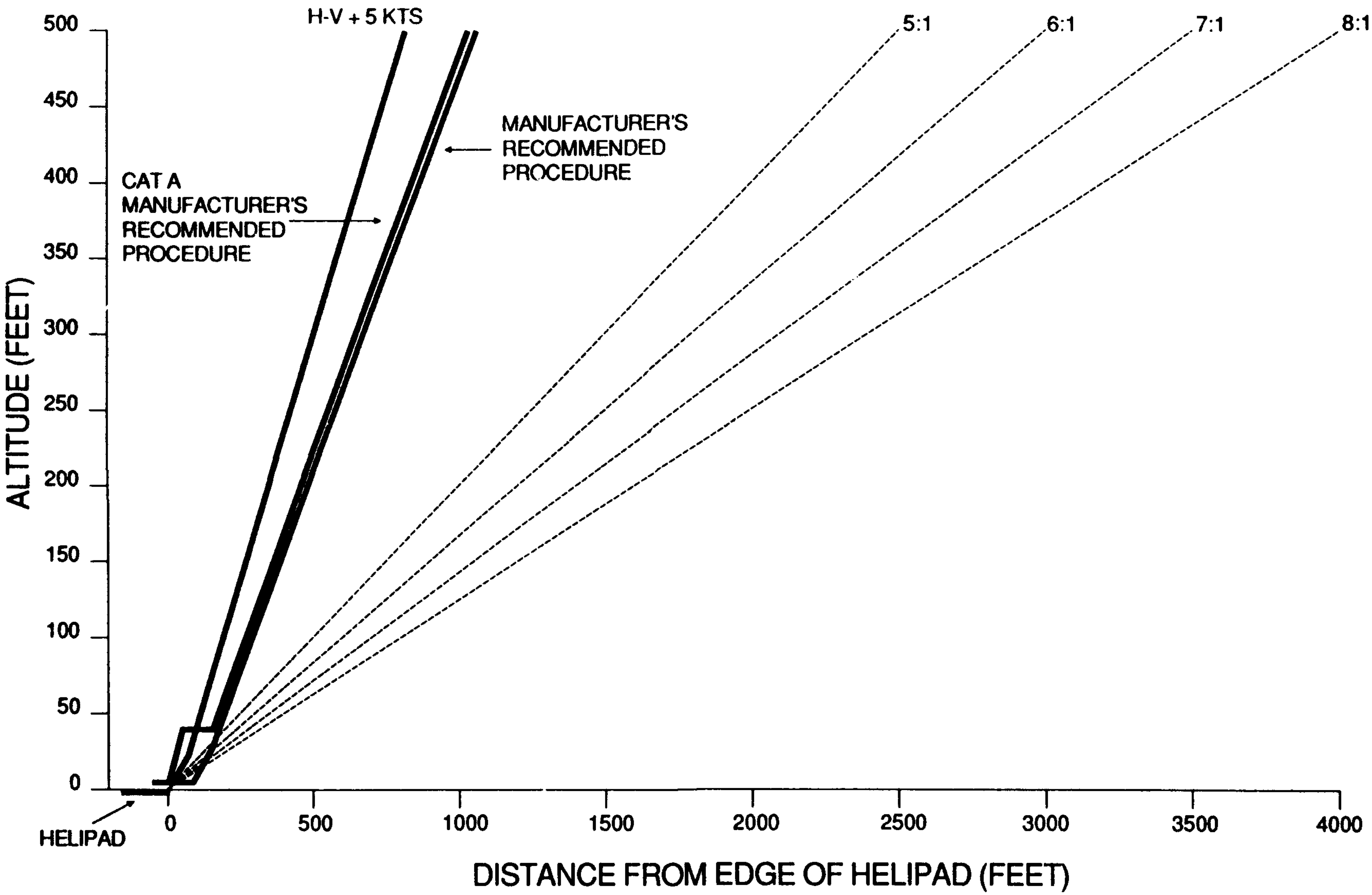
S 76A DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL, HOT DAY



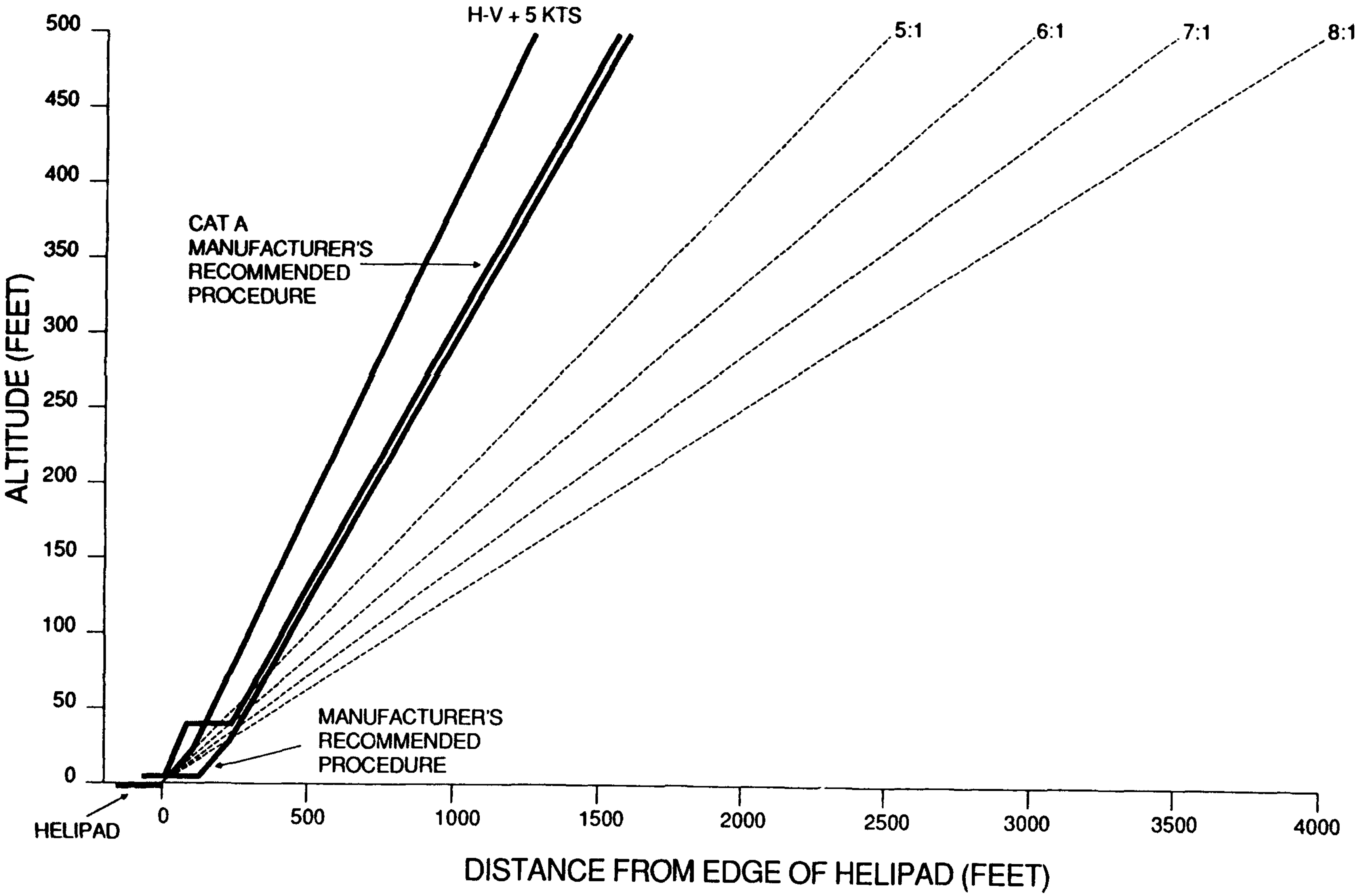
S 76A DEPARTURE PROFILES

70% MAX. G.W., 2000 FEET, STANDARD DAY



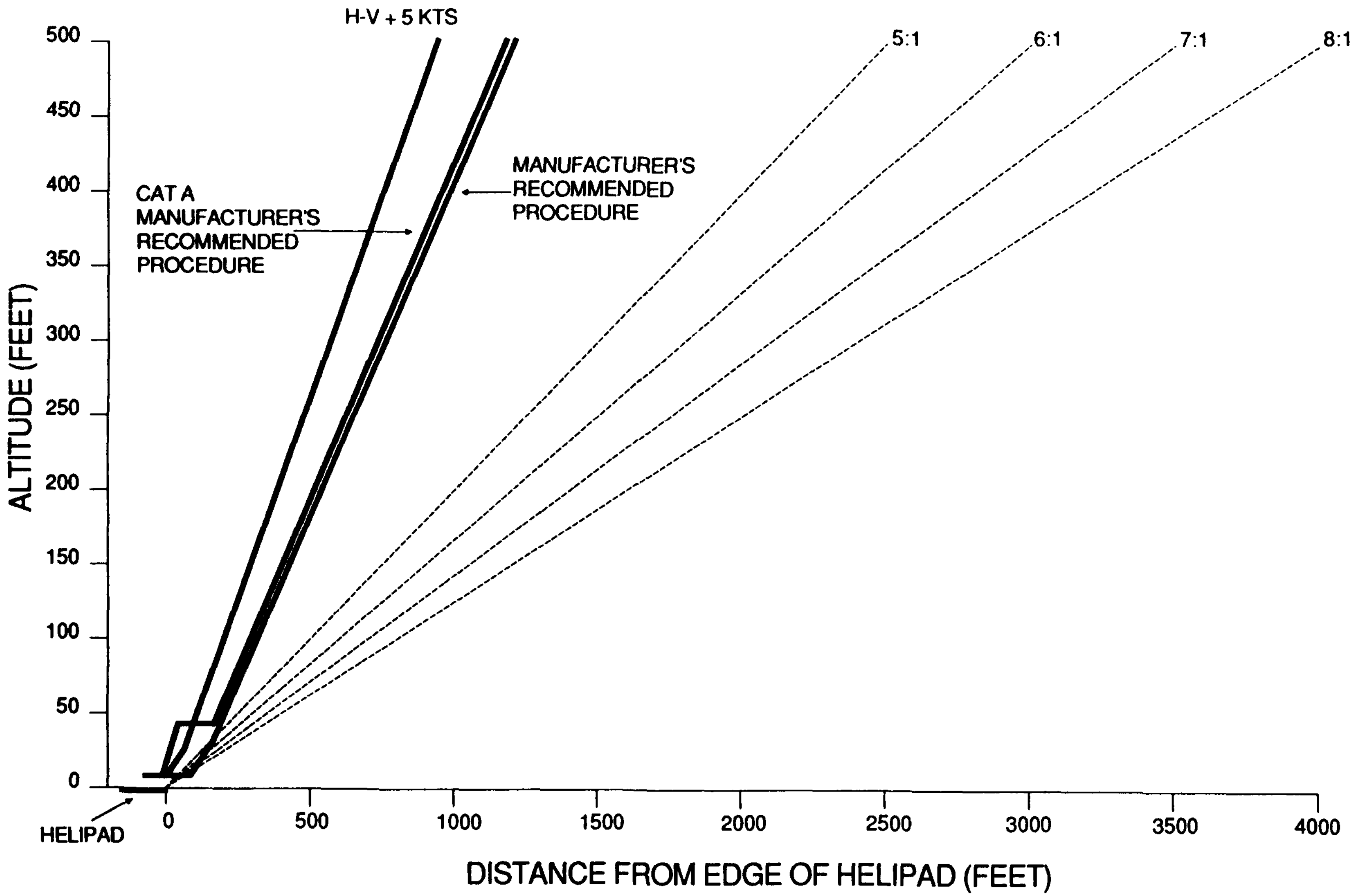
S 76A DEPARTURE PROFILES

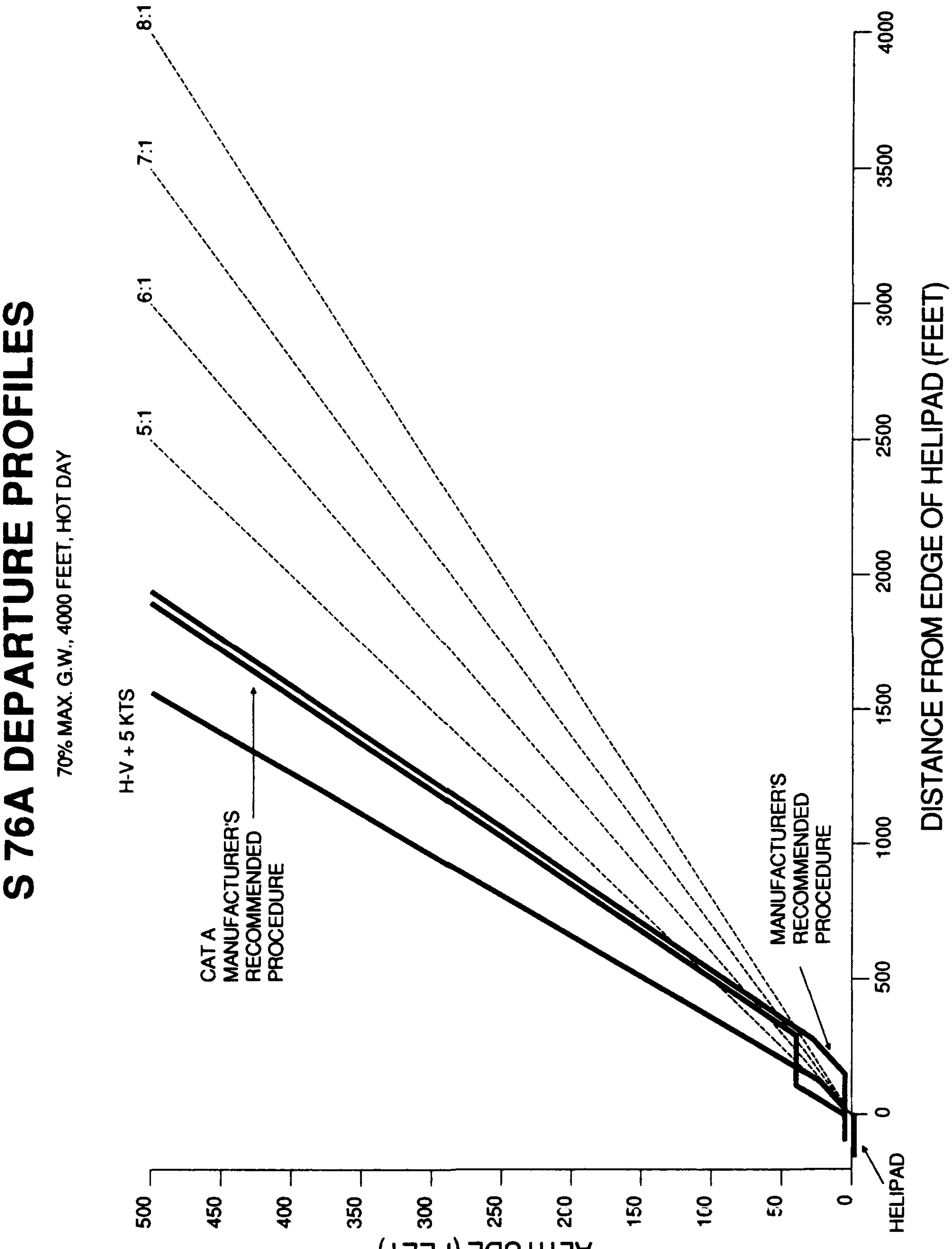
70% MAX. G.W., 2000 FEET, HOT DAY



S 76A DEPARTURE PROFILES

70% MAX. G.W., 4000 FEET, STANDARD DAY

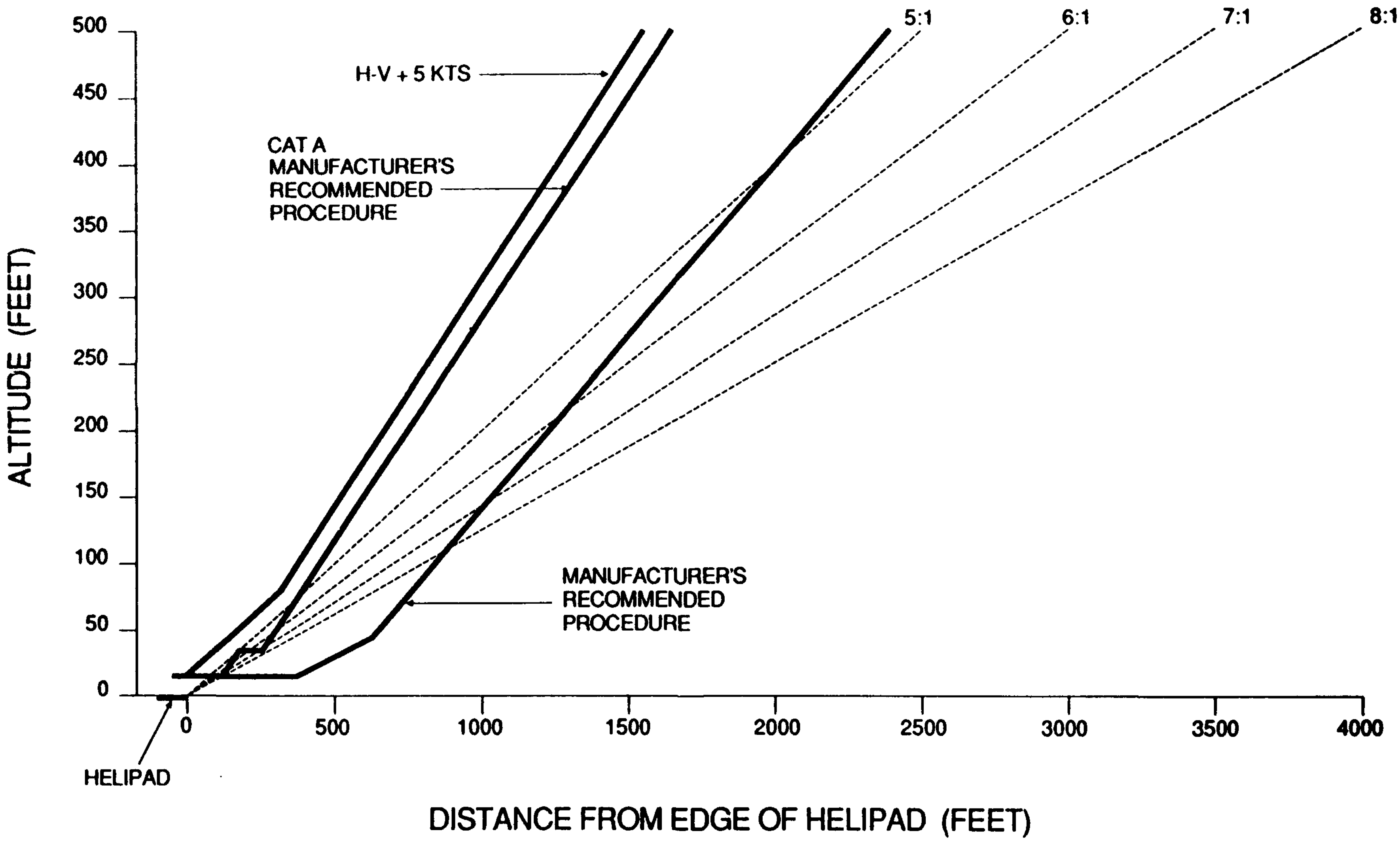




S 76A DEPARTURE PROFILES
70% MAX. G.W., 4000 FEET, HOT DAY
H-V + 5 KTS
CAT A MANUFACTURER'S RECOMMENDED PROCEDURE
MANUFACTURER'S RECOMMENDED PROCEDURE
5:1
6:1
7:1
8:1
HELIPAD
ALTITUDE (FEET)
0
50
100
150
200
250
300
350
400
450
500
DISTANCE FROM EDGE OF HELIPAD (FEET)
0
500
1000
1500
2000
2500
3000
3500
4000

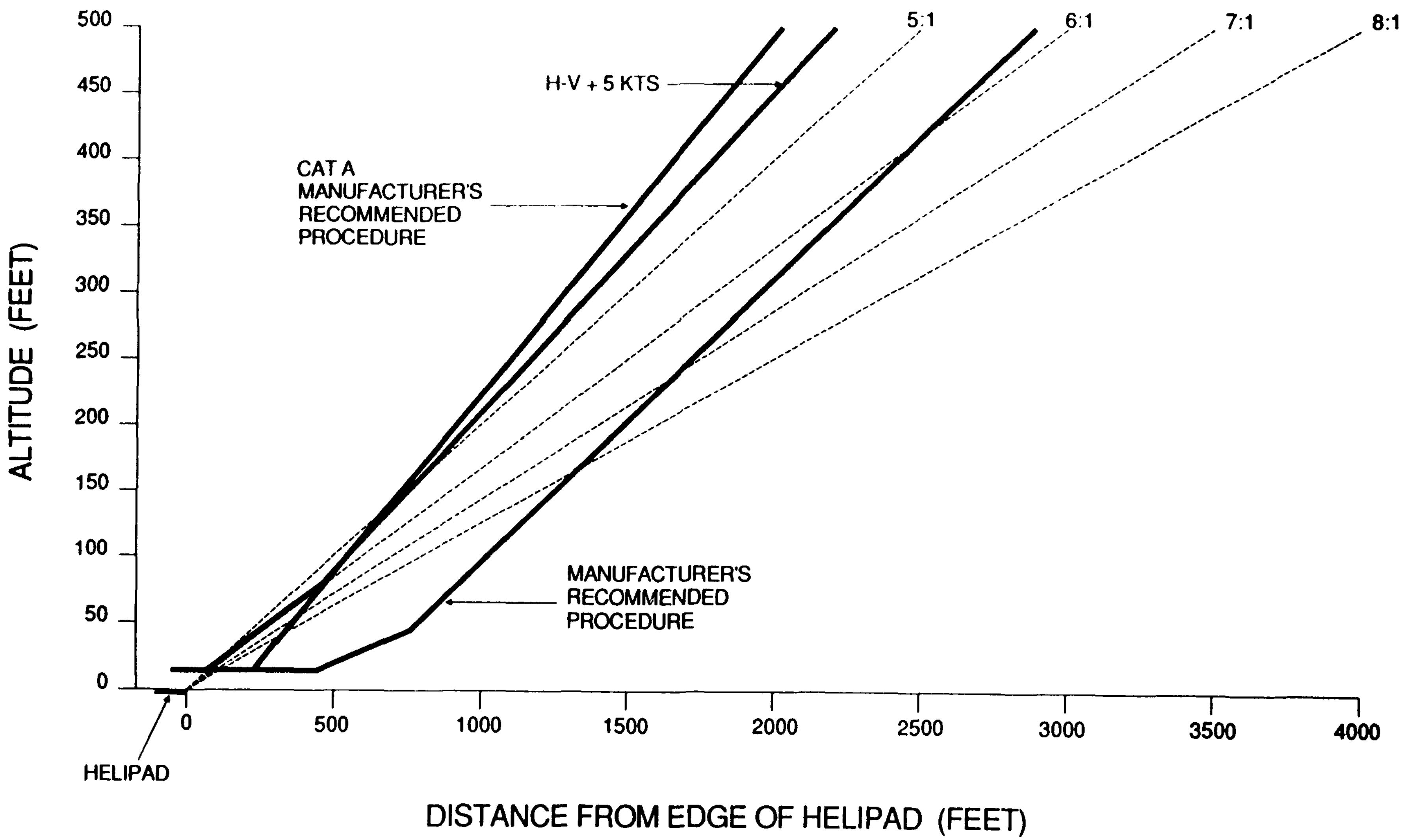
AS 332C DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, STANDARD DAY



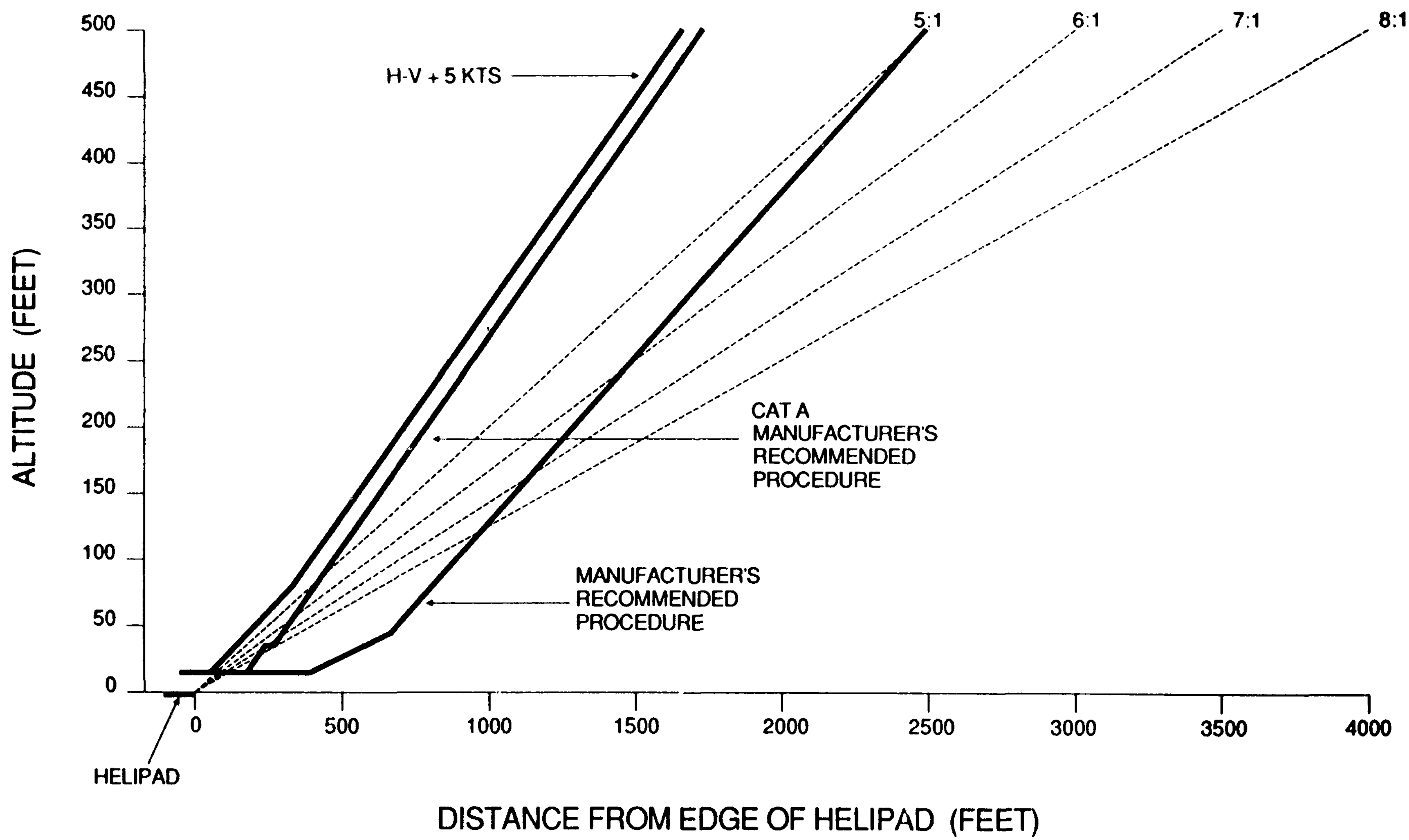
AS 332C DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, HOT DAY



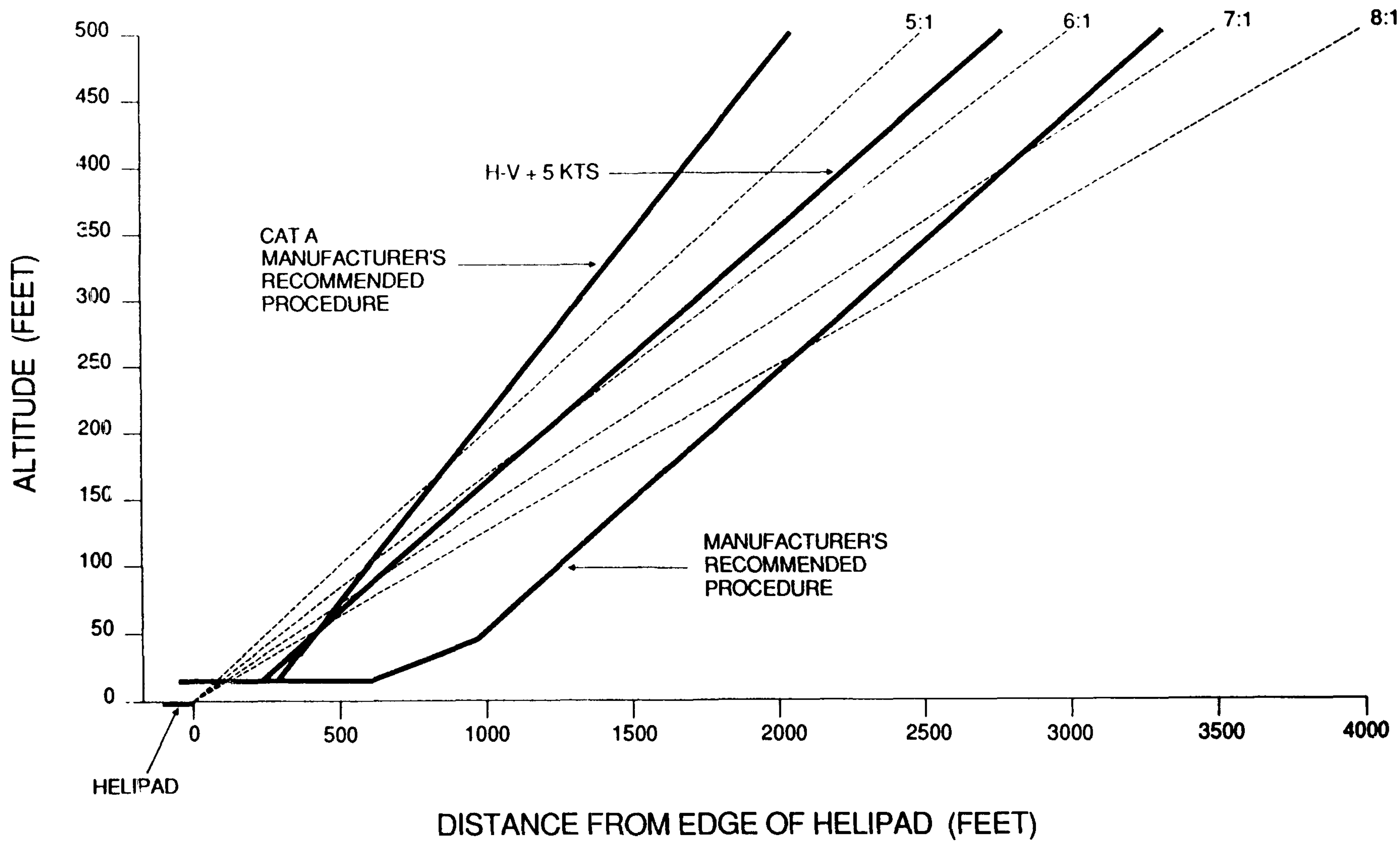
AS 332C DEPARTURE PROFILES

MAX. G.W., 2000 FEET, STANDARD DAY



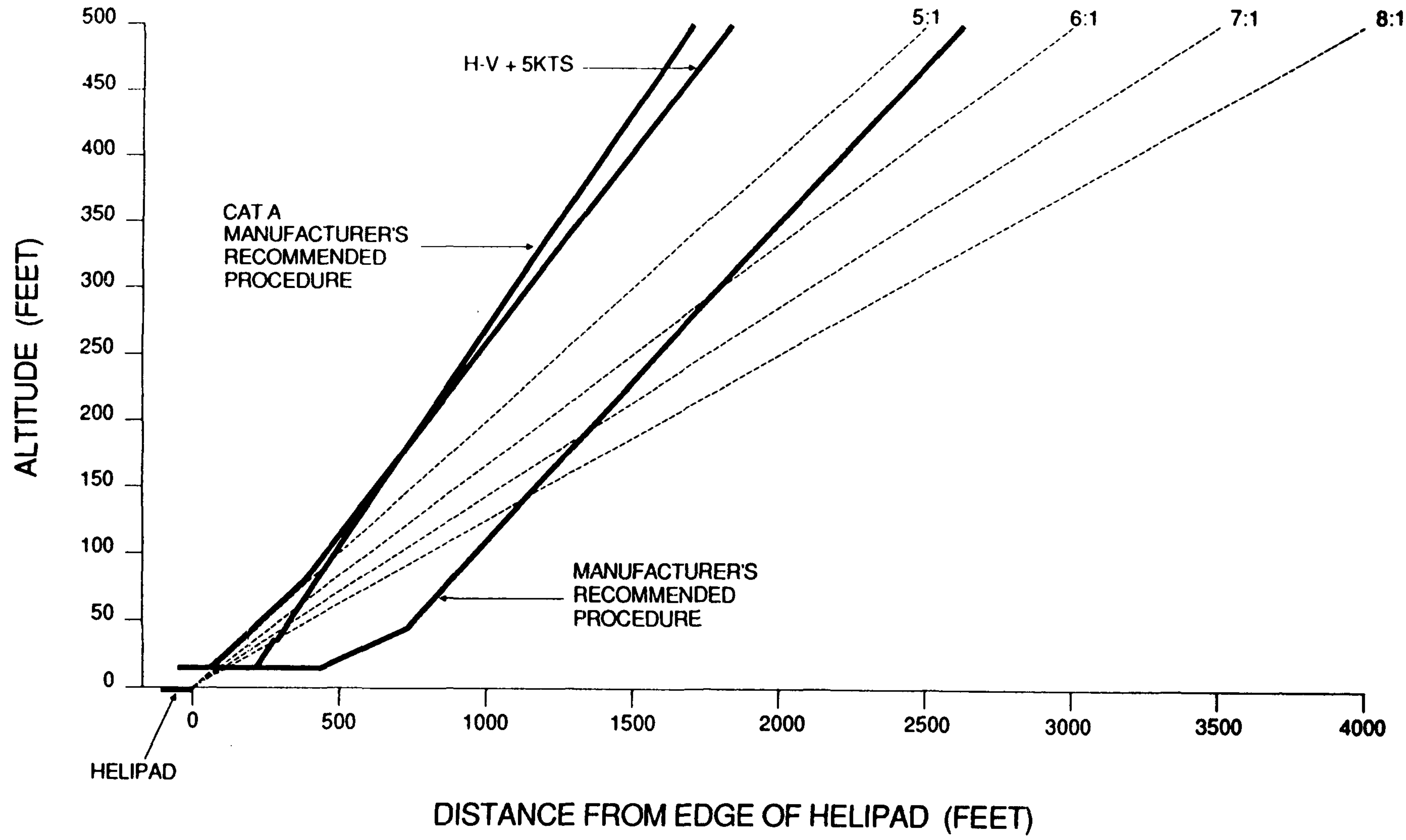
AS 332C DEPARTURE PROFILES

MAX. G.W., 2000 FEET, HOT DAY



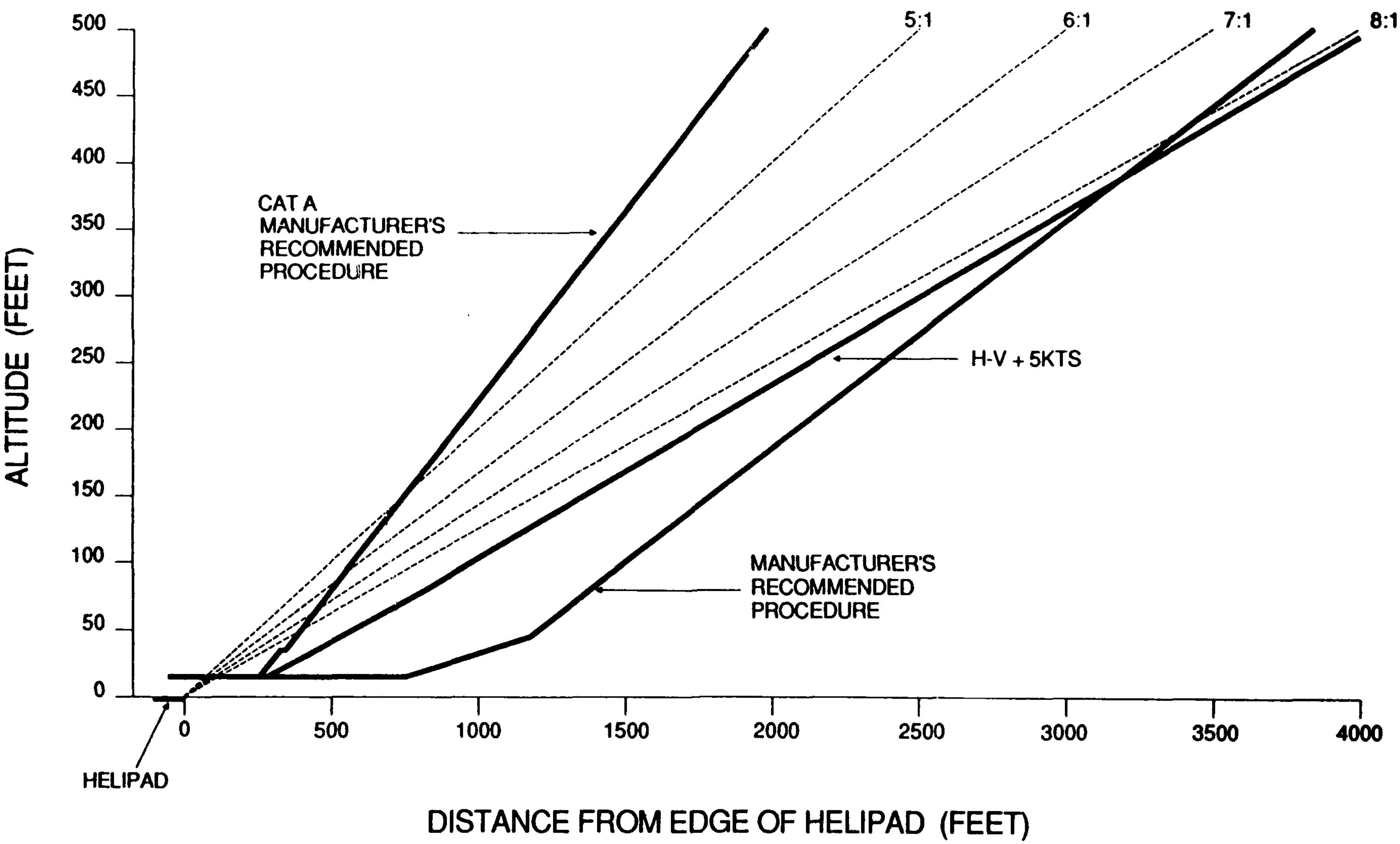
AS 332C DEPARTURE PROFILES

MAX. G.W., 4000 FEET, STANDARD DAY



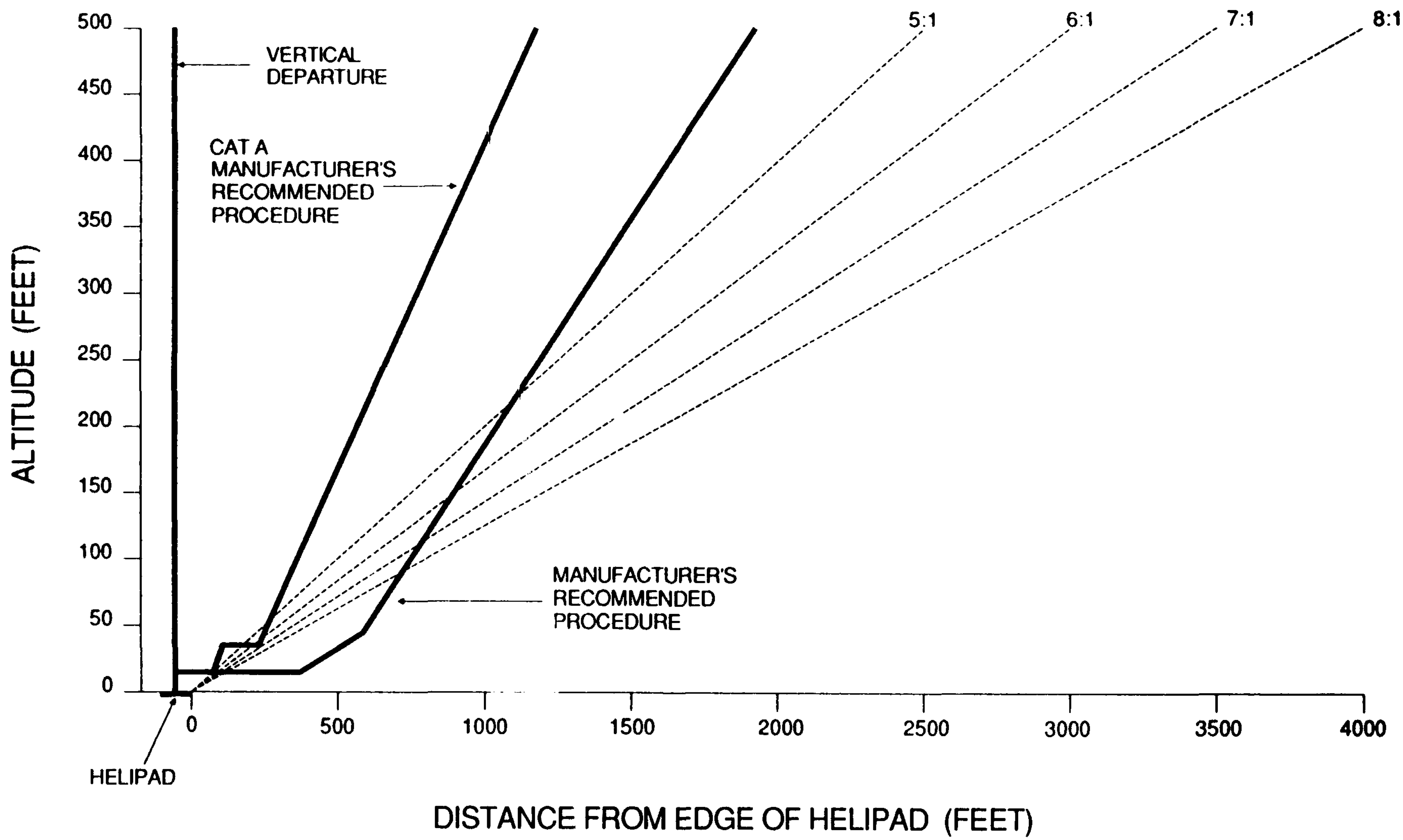
AS 332C DEPARTURE PROFILES

MAX. G.W., 4000 FEET, HOT DAY



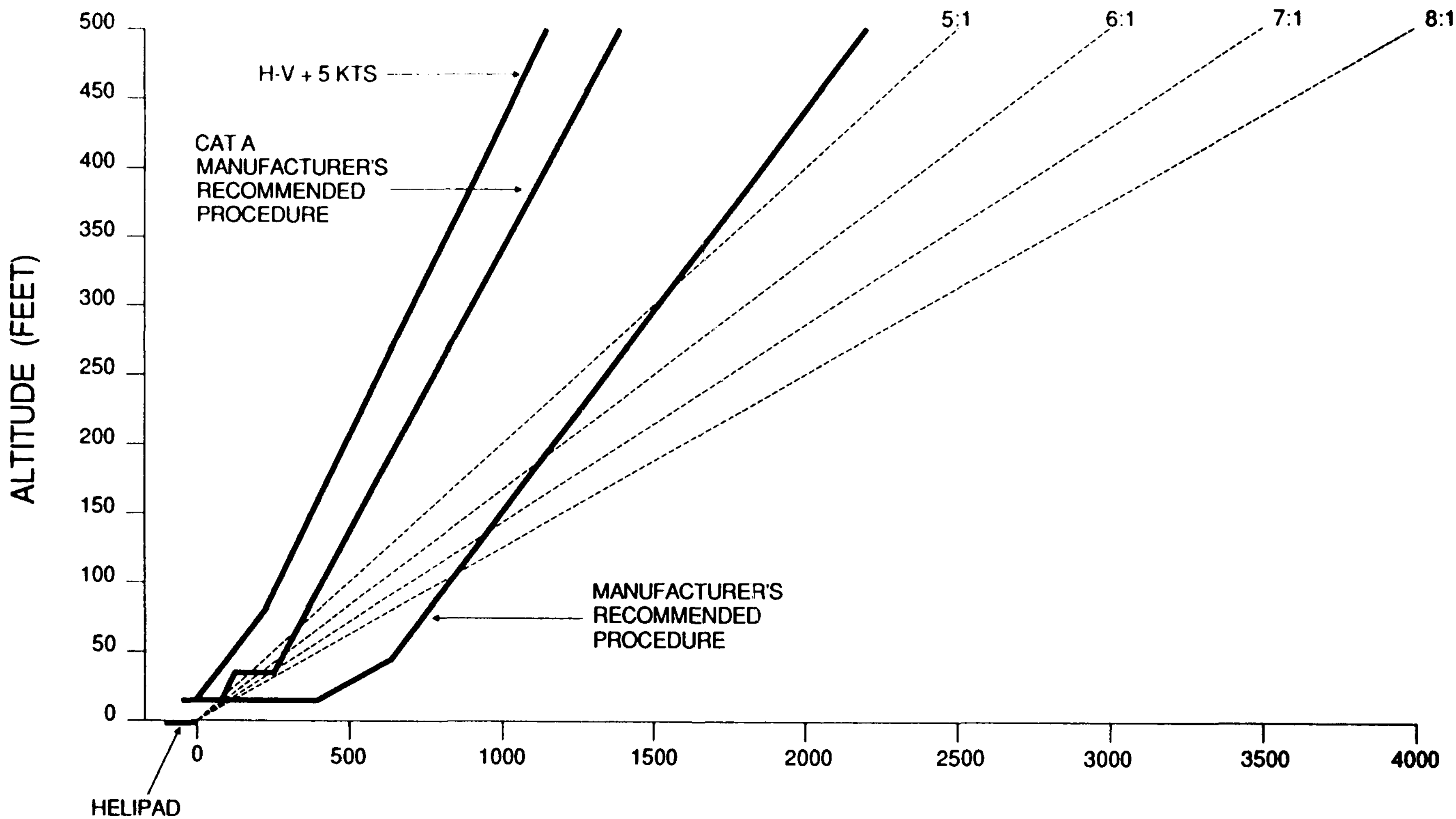
AS 332C DEPARTURE PROFILES

85% MAX. G.W., SEA LEVEL, STANDARD DAY



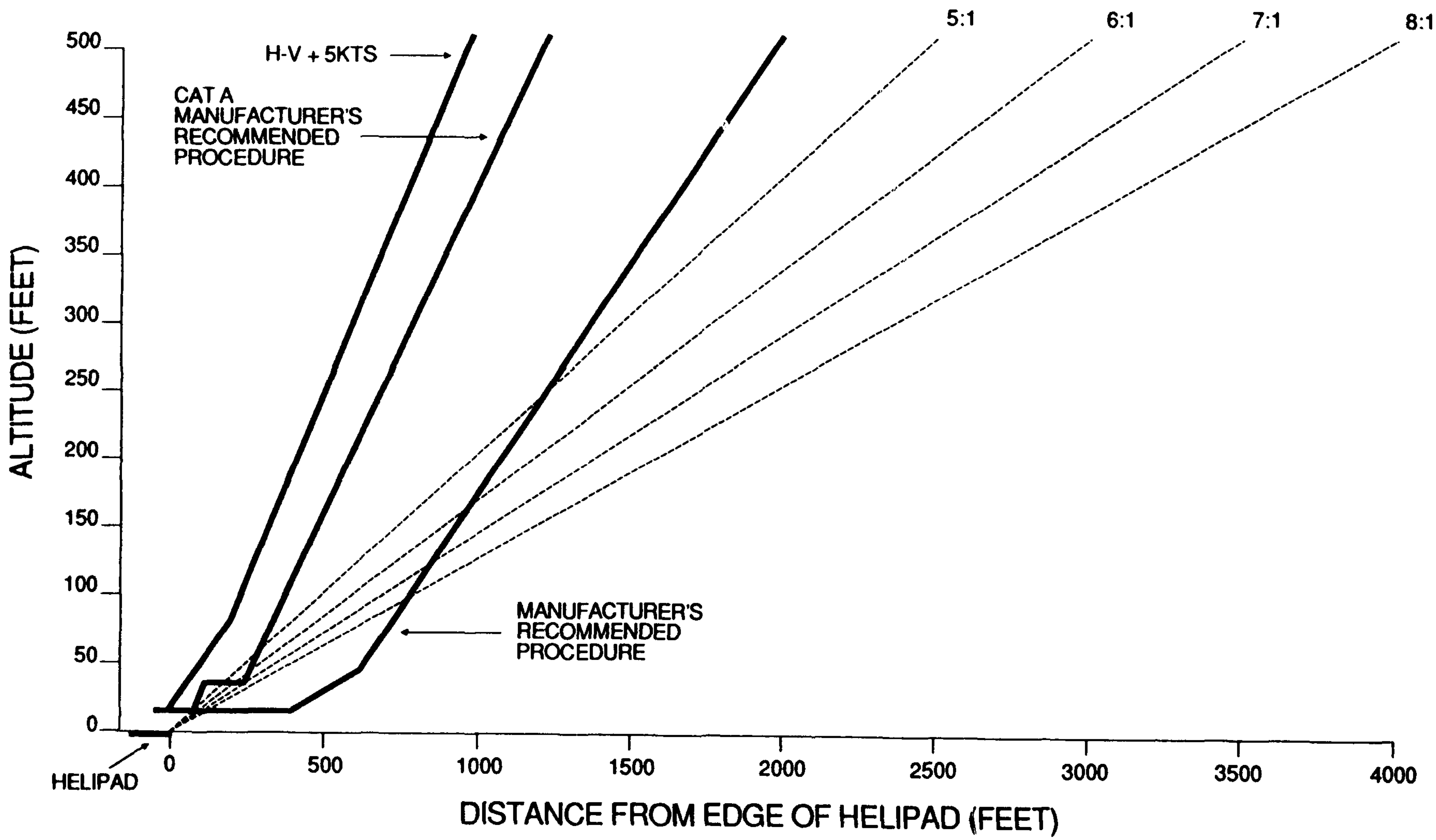
AS 332C DEPARTURE PROFILES

85% MAX. G.W., SEA LEVEL, HOT DAY



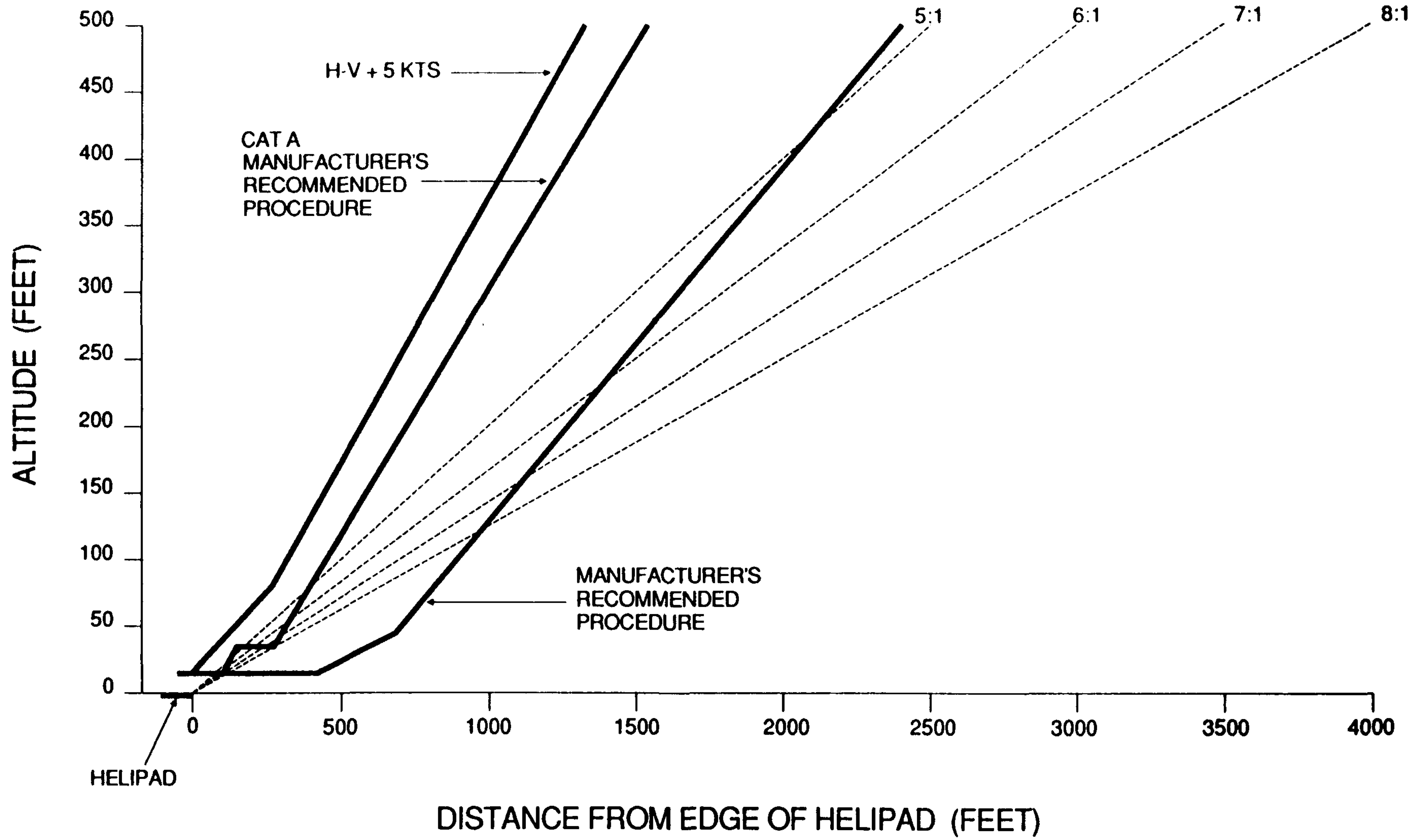
AS 332C DEPARTURE PROFILES

85% MAX. G.W., 2000 FEET, STANDARD DAY



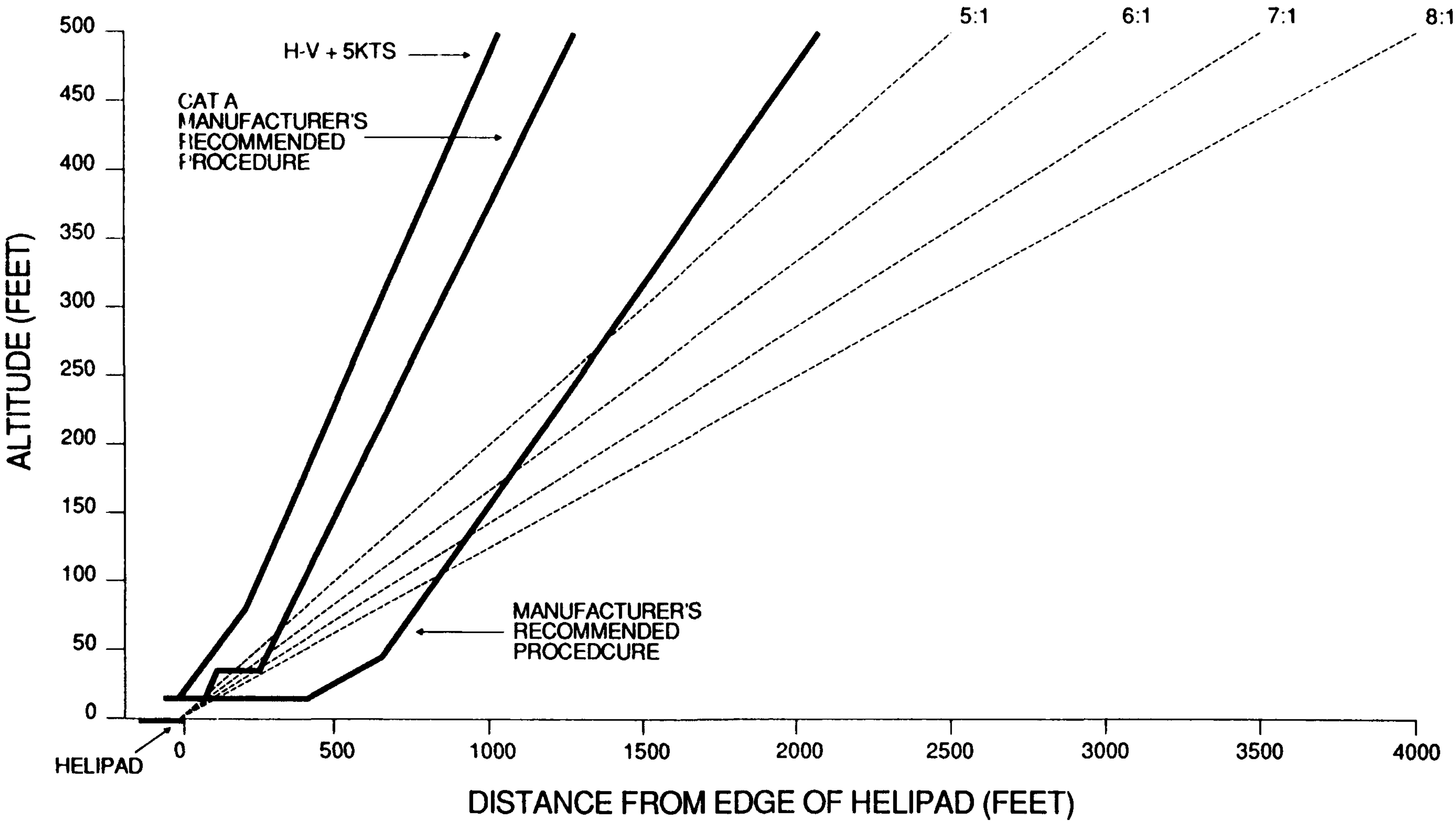
AS 332C DEPARTURE PROFILES

85% MAX. G.W., 2000 FEET, HOT DAY



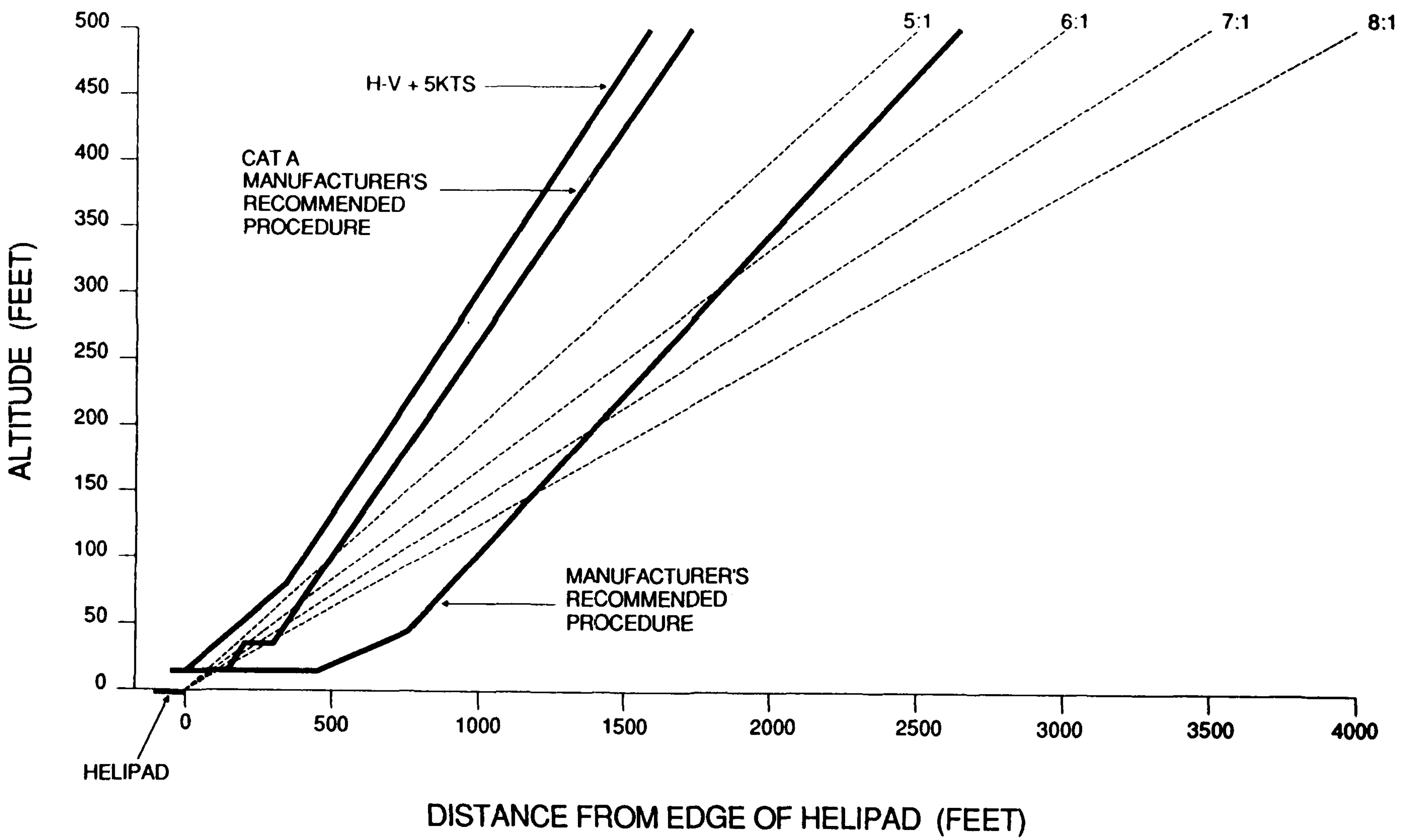
AS 322C DEPARTURE PROFILES

85% MAX. G.W., 4000 FEET, STANDARD DAY



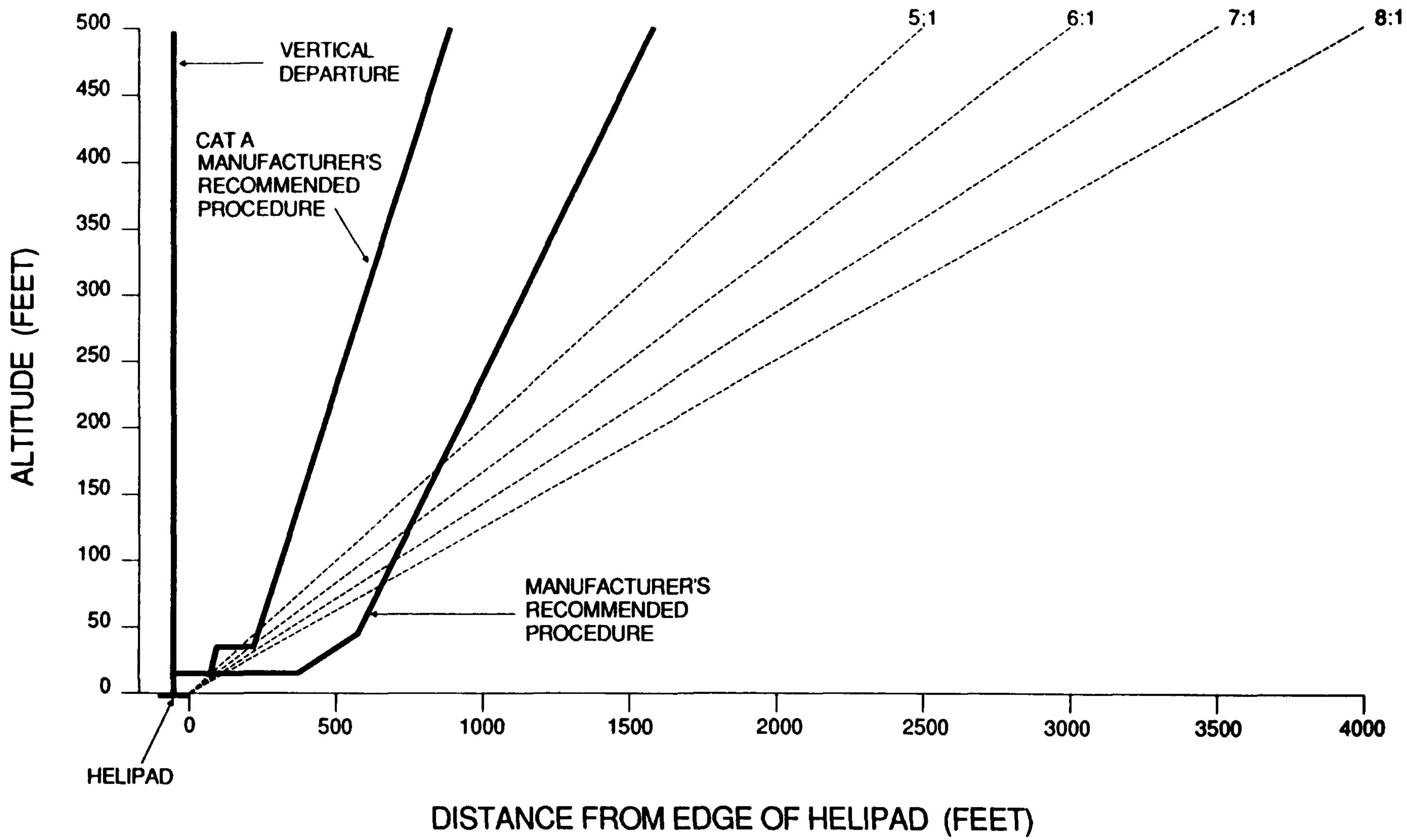
AS 332C DEPARTURE PROFILES

85% MAX. G.W., 4000 FEET, HOT DAY



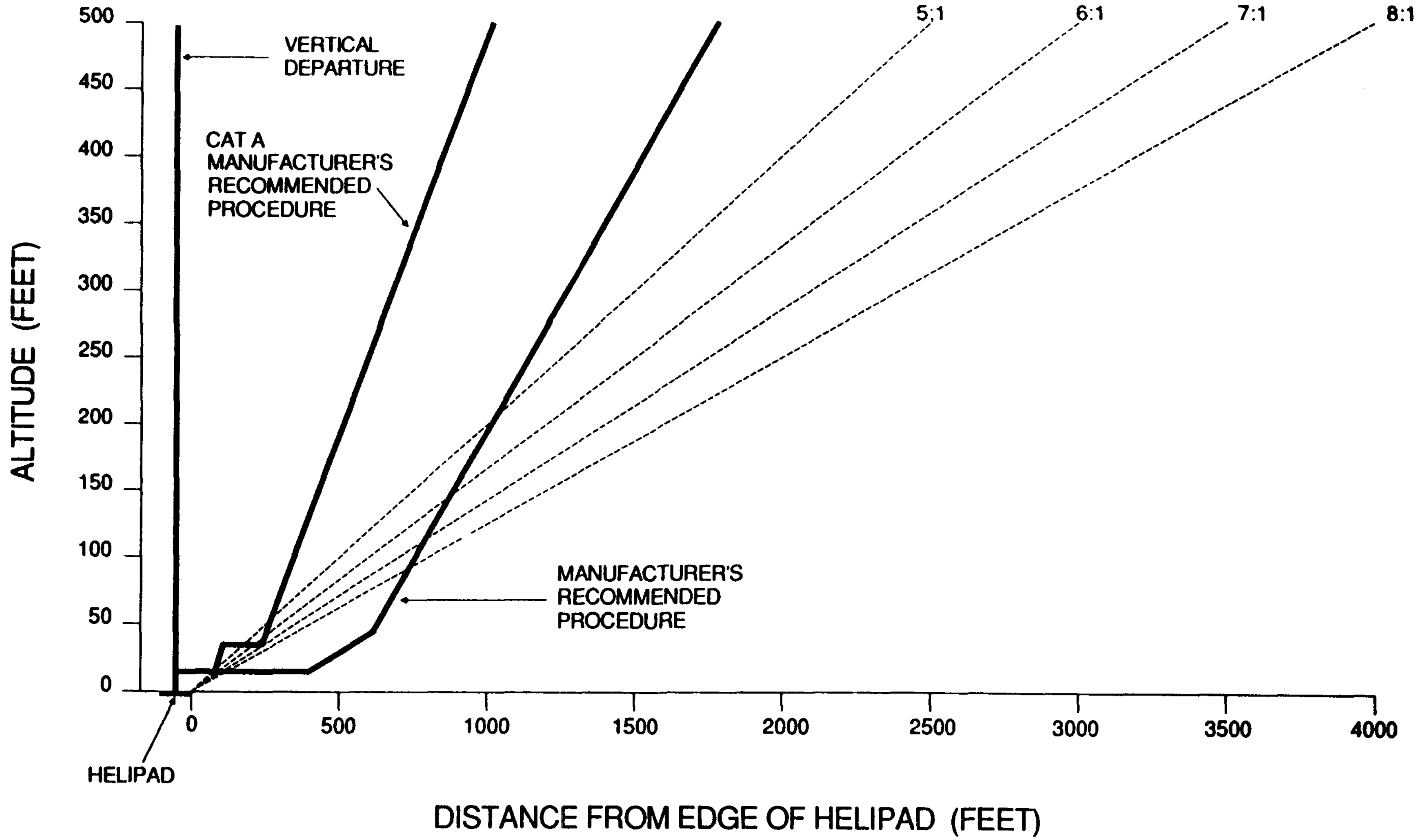
AS 332C DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL, STANDARD DAY



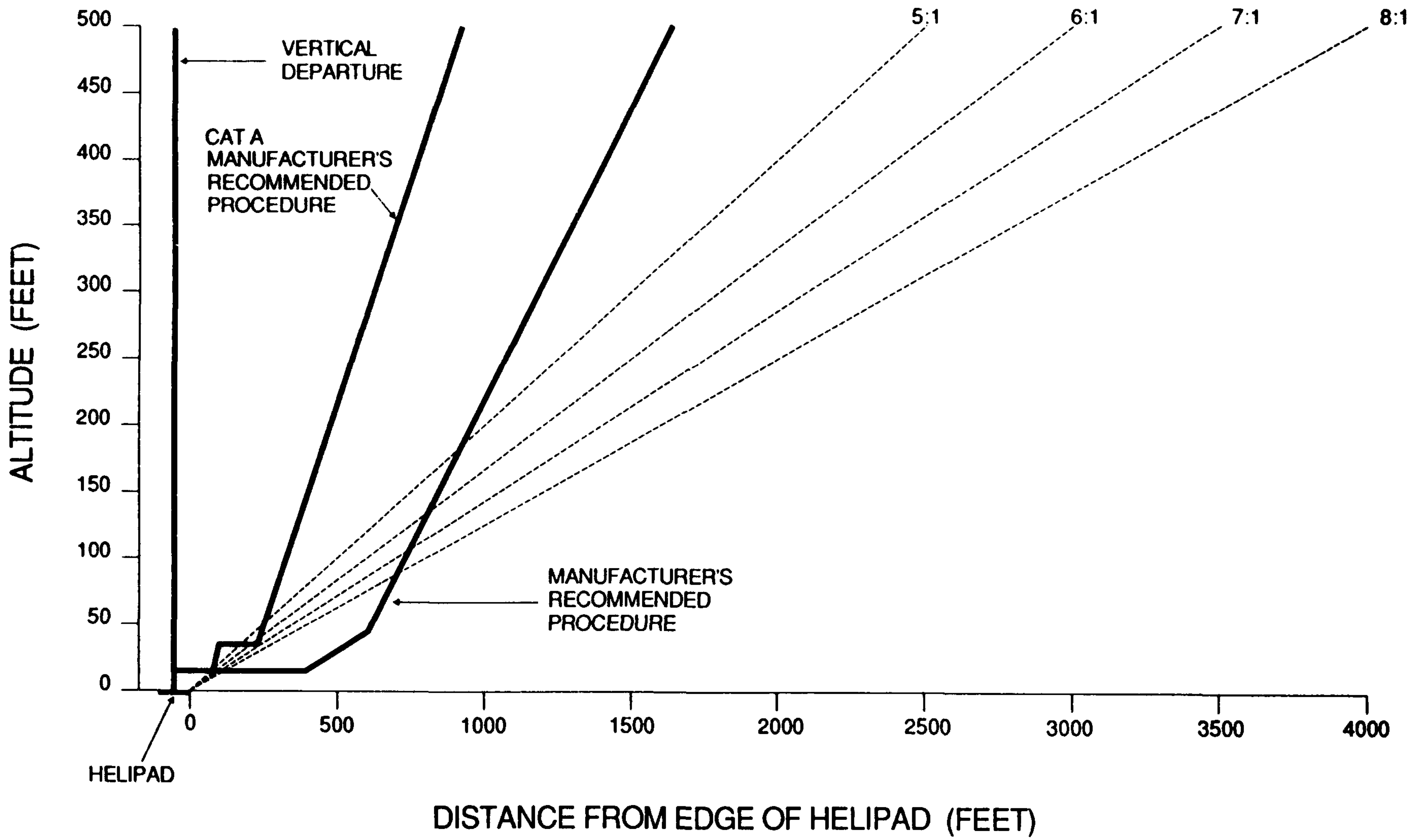
AS 332C DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL, HOT DAY



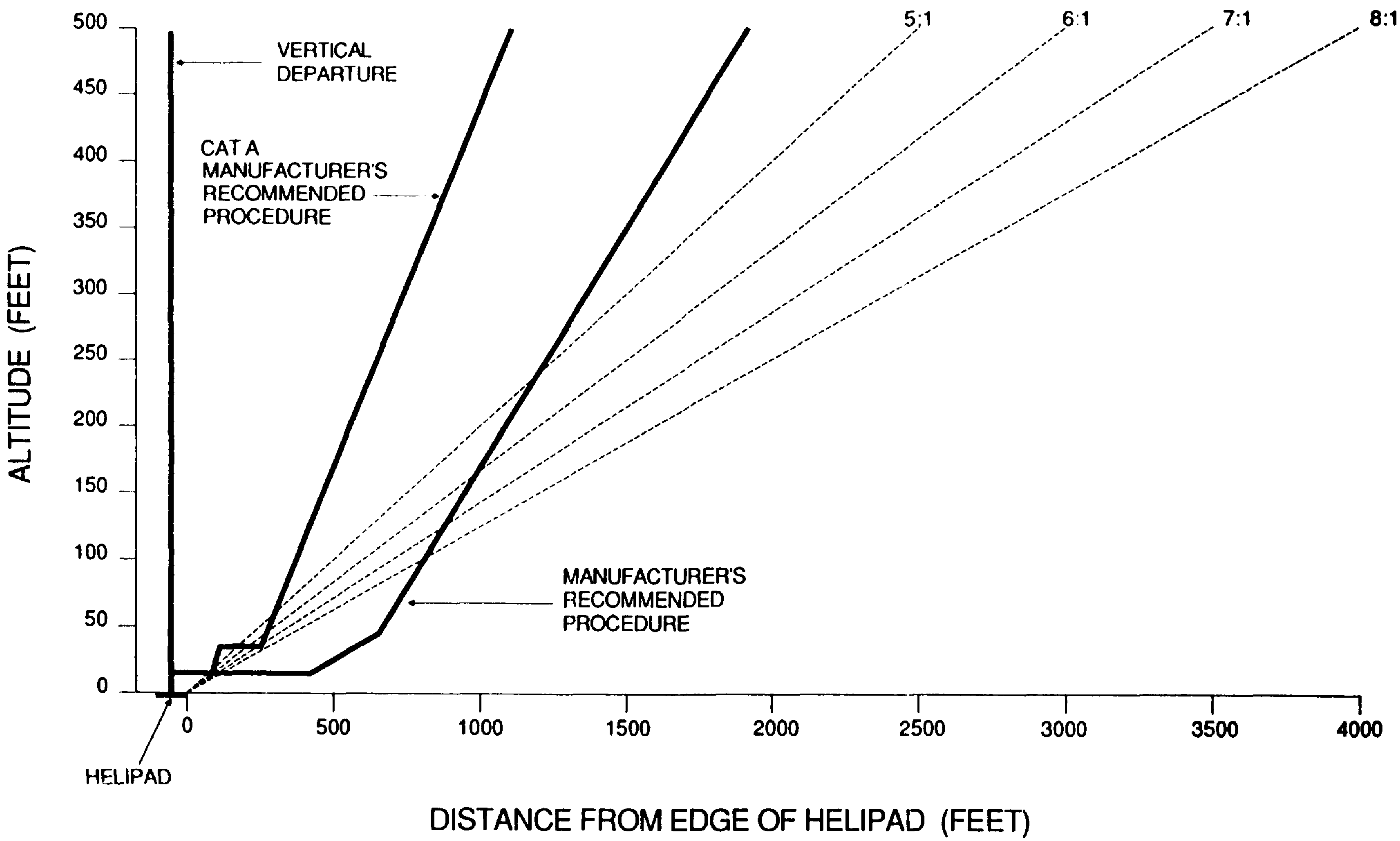
AS 332C DEPARTURE PROFILES

70% MAX. G.W., 2000 FEET, STANDARD DAY



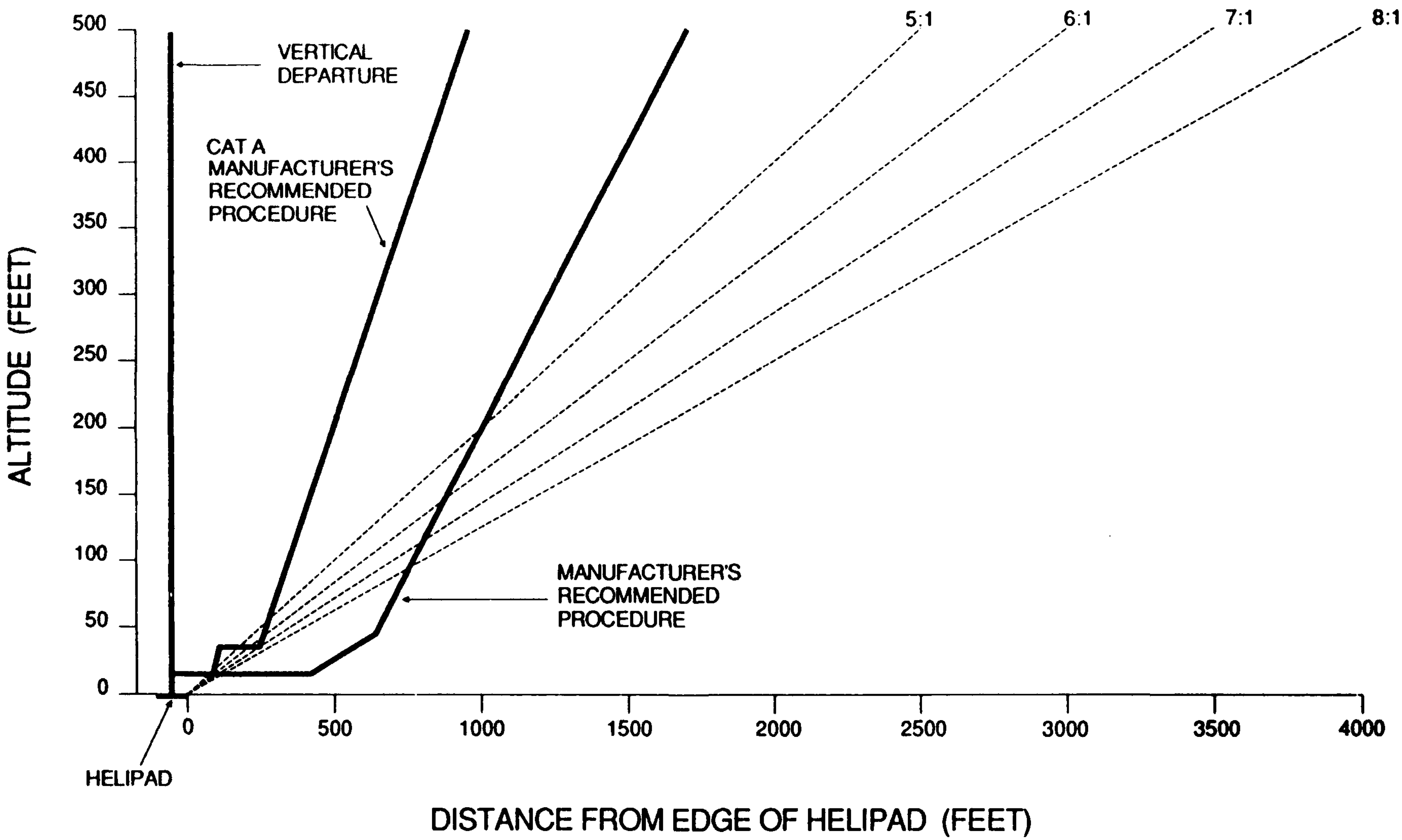
AS 332C DEPARTURE PROFILES

70% MAX. G.W., 2000 FEET, HOT DAY



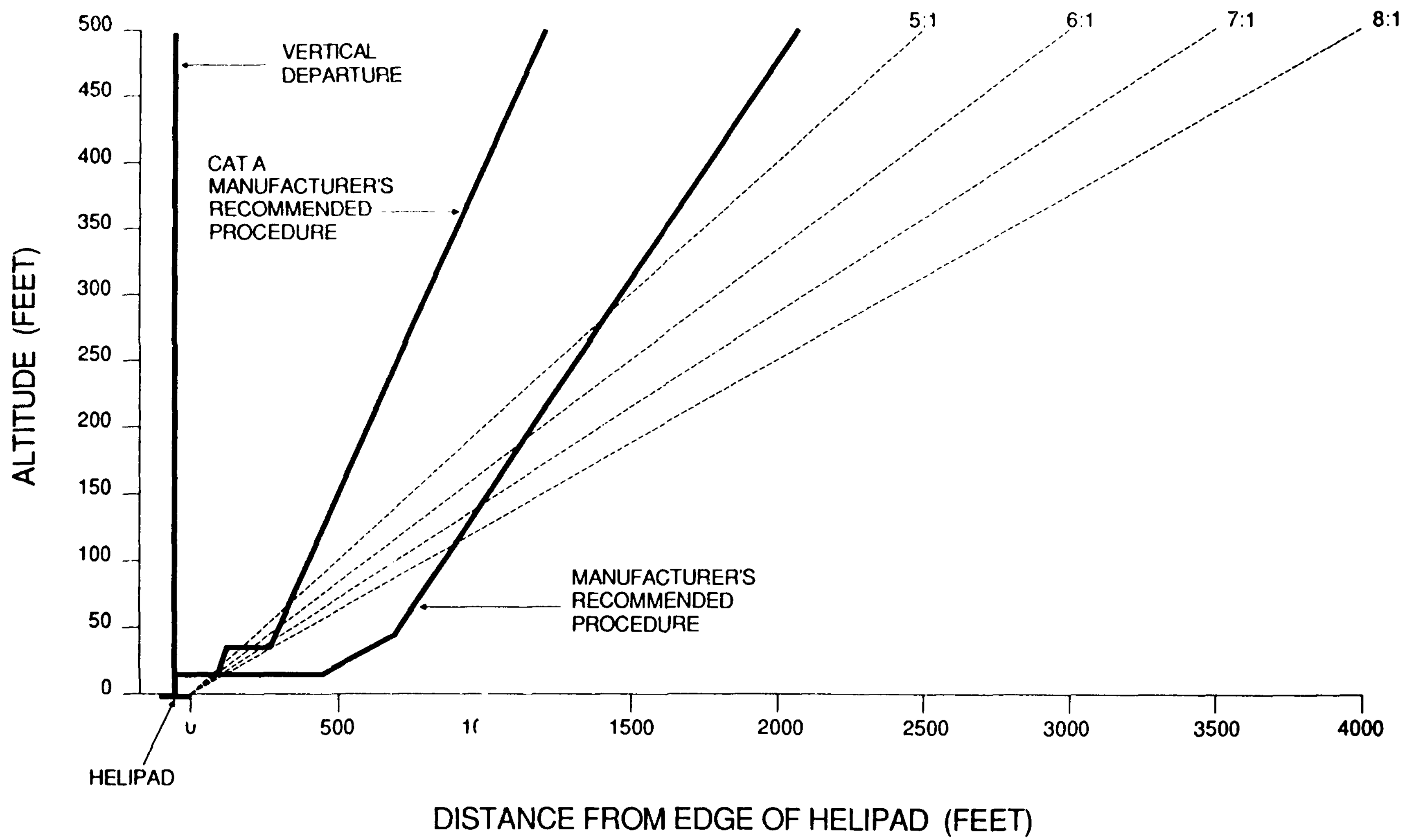
AS 332C DEPARTURE PROFILES

70% MAX. G.W., 4000 FEET, STANDARD DAY



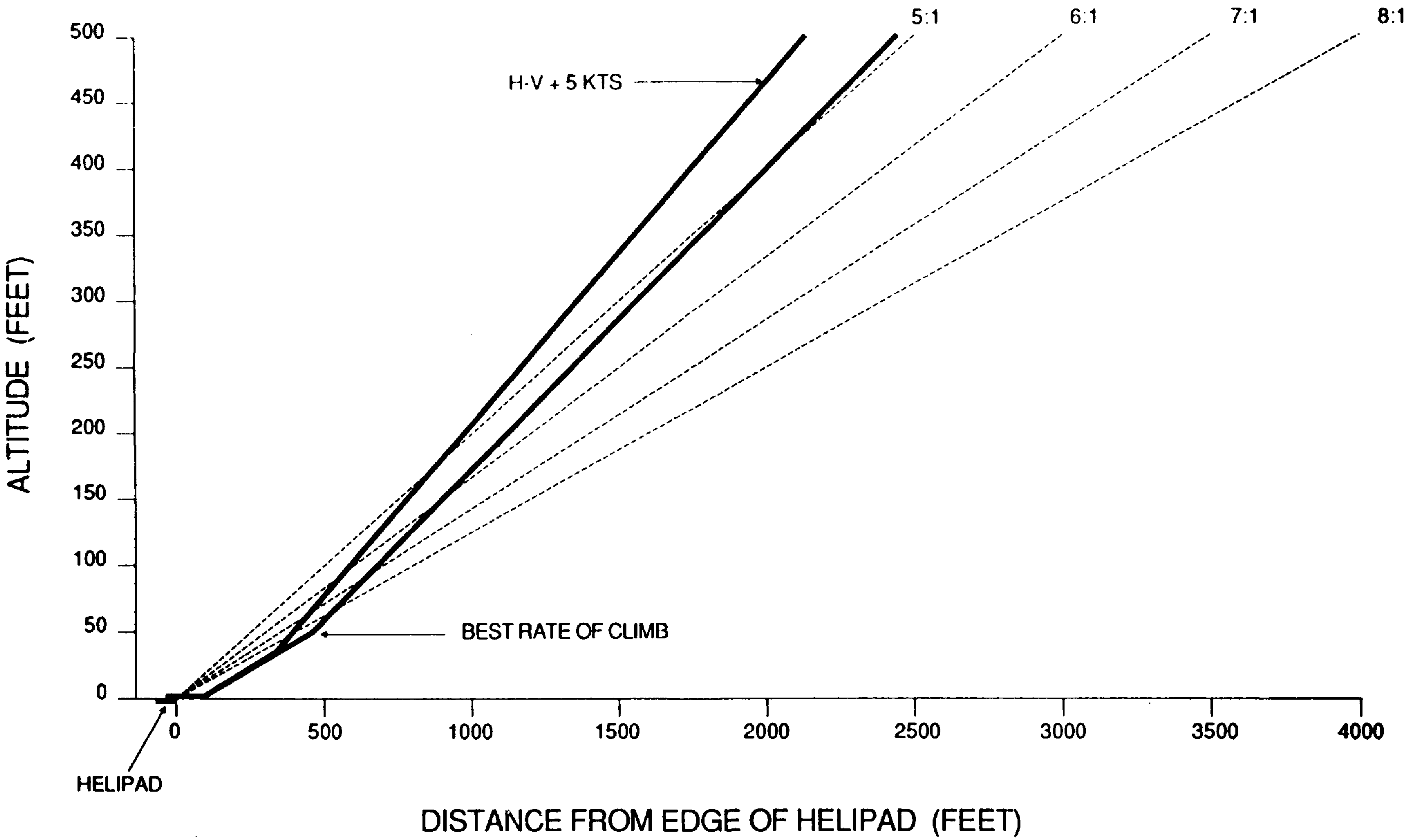
AS 332C DEPARTURE PROFILES

70% MAX. G.W., 4000 FEET, HOT DAY



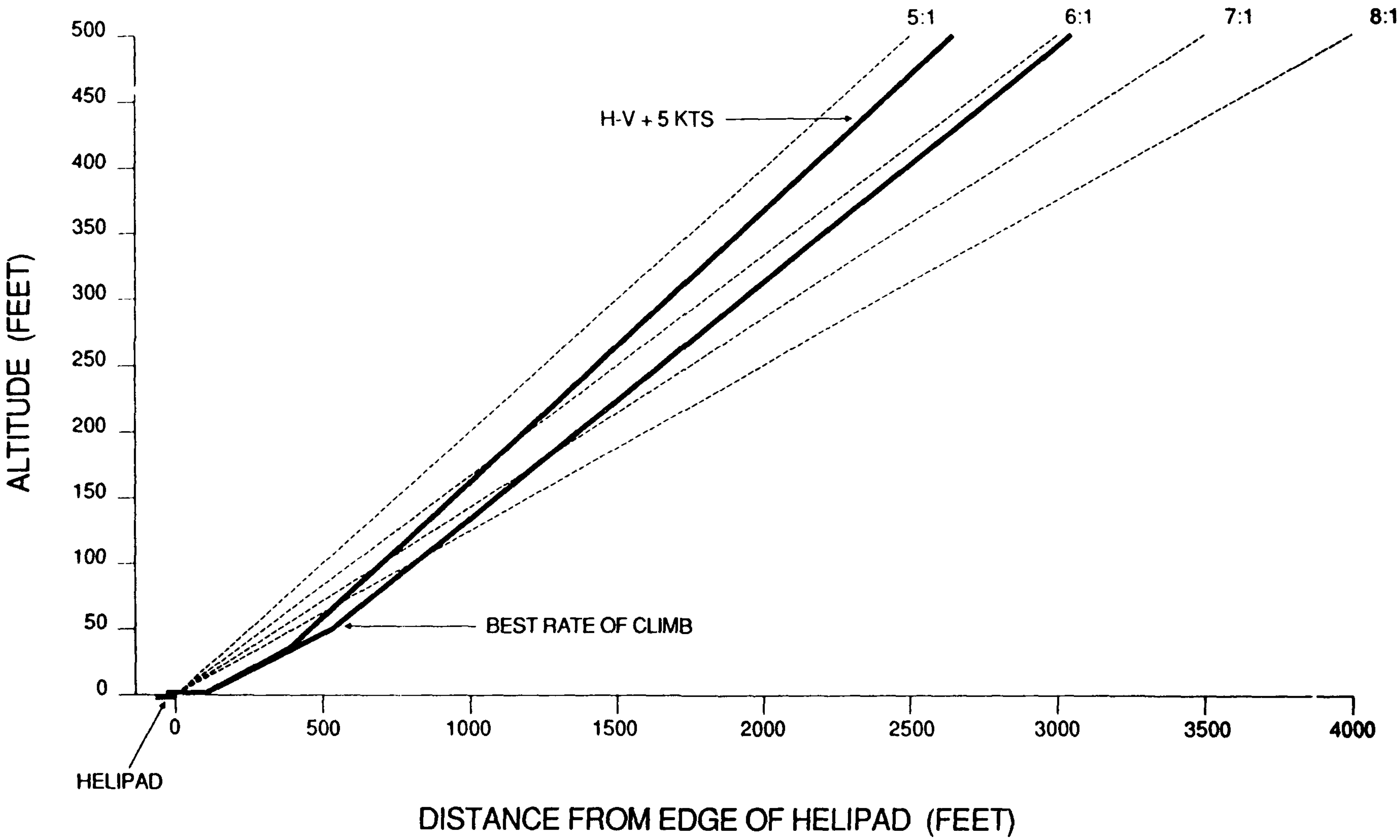
B 206B III DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, STANDARD DAY



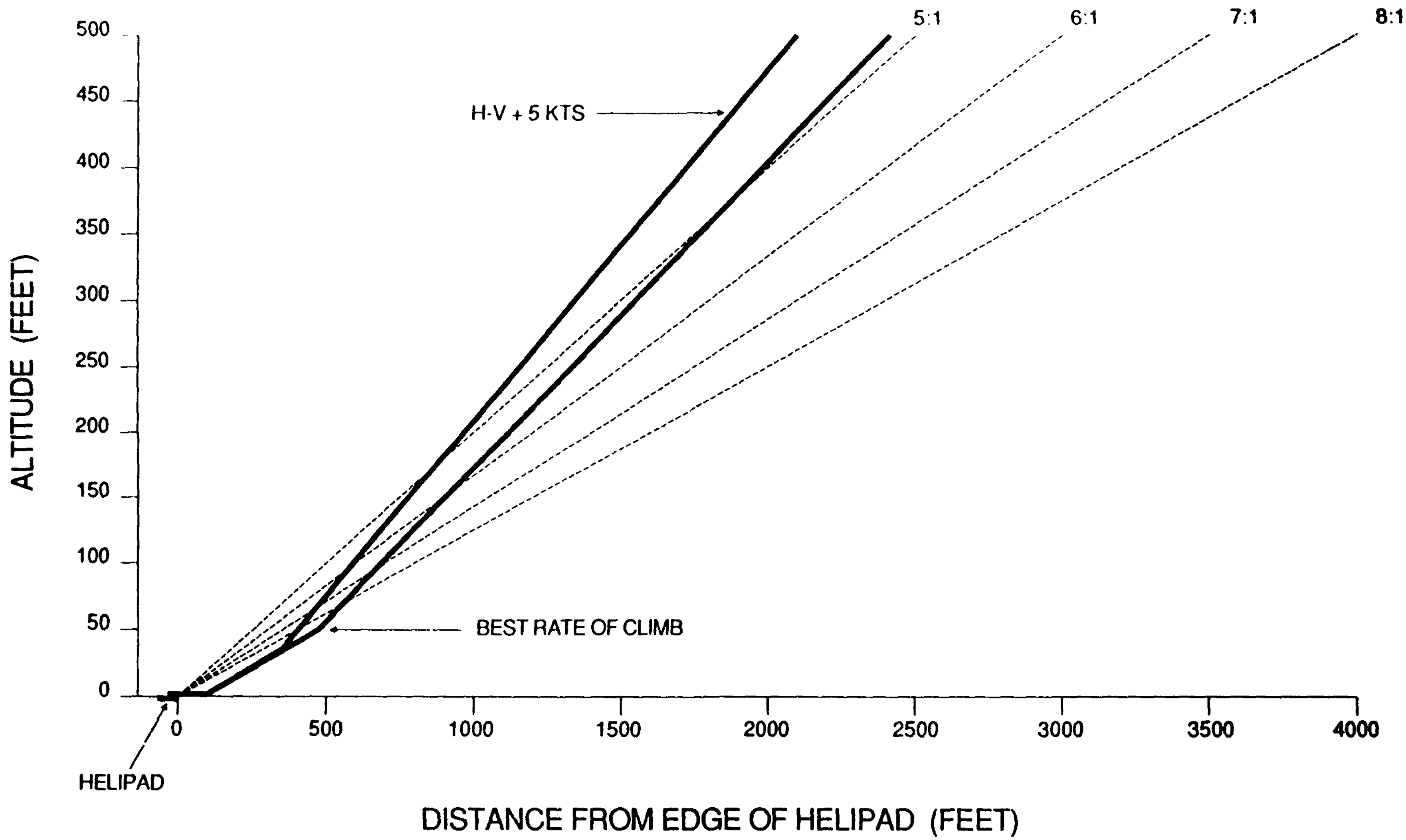
B 206B III DEPARTURE PROFILES

MAX. G.W., SEA LEVEL, HOT DAY



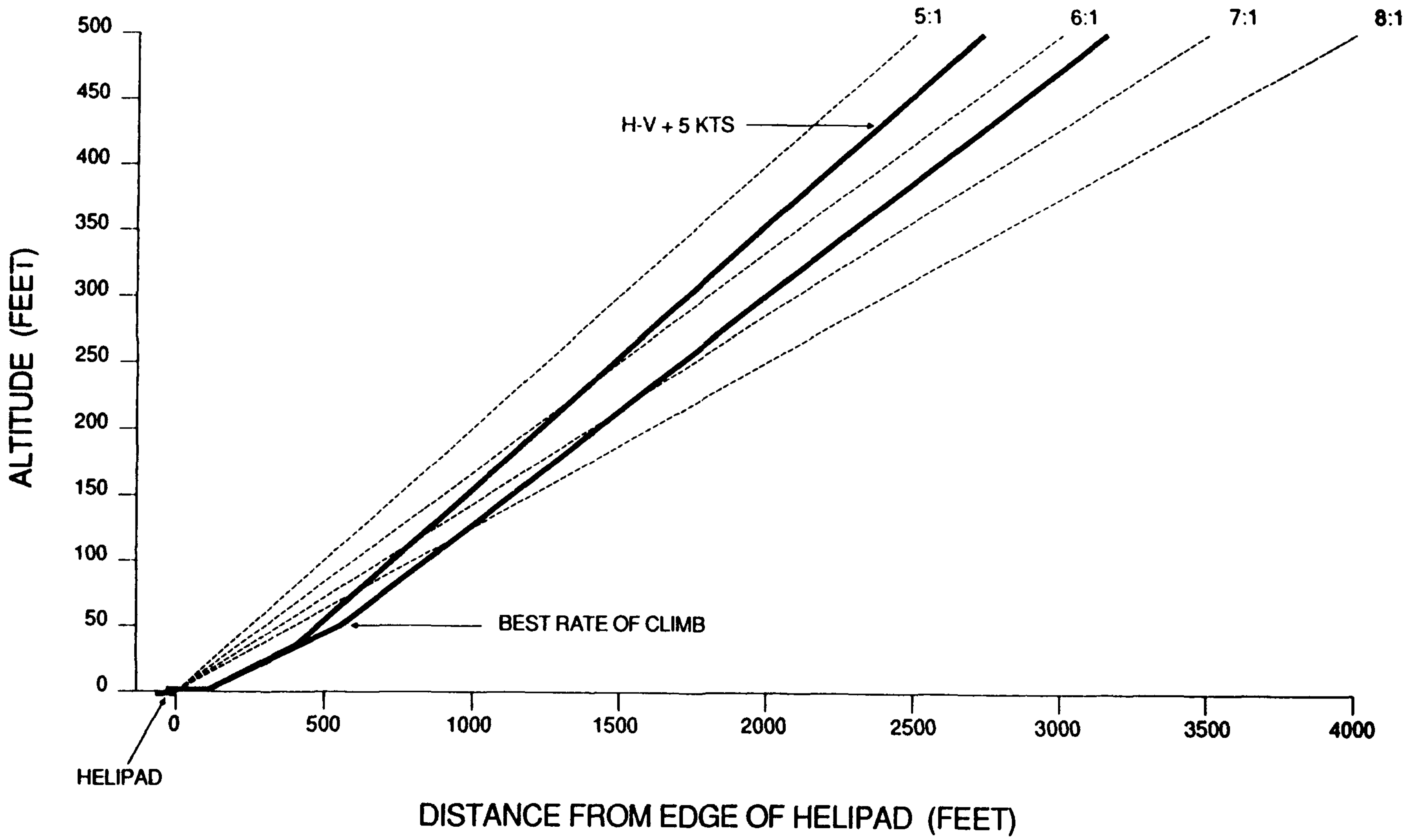
B 206B III DEPARTURE PROFILES

MAX. G.W., 2000 FEET, STANDARD DAY



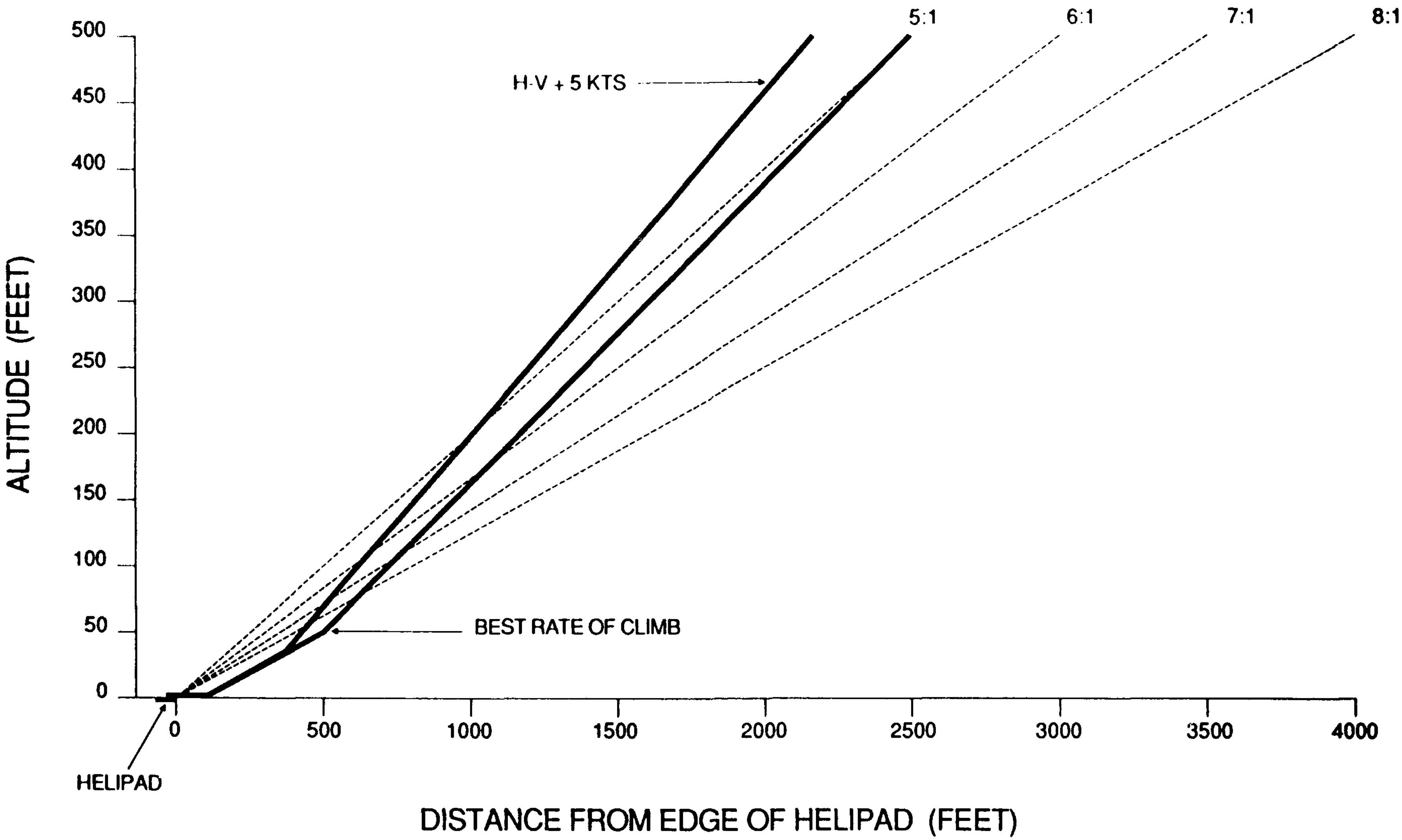
B 206B III DEPARTURE PROFILES

MAX. G.W., 2000 FEET, HOT DAY



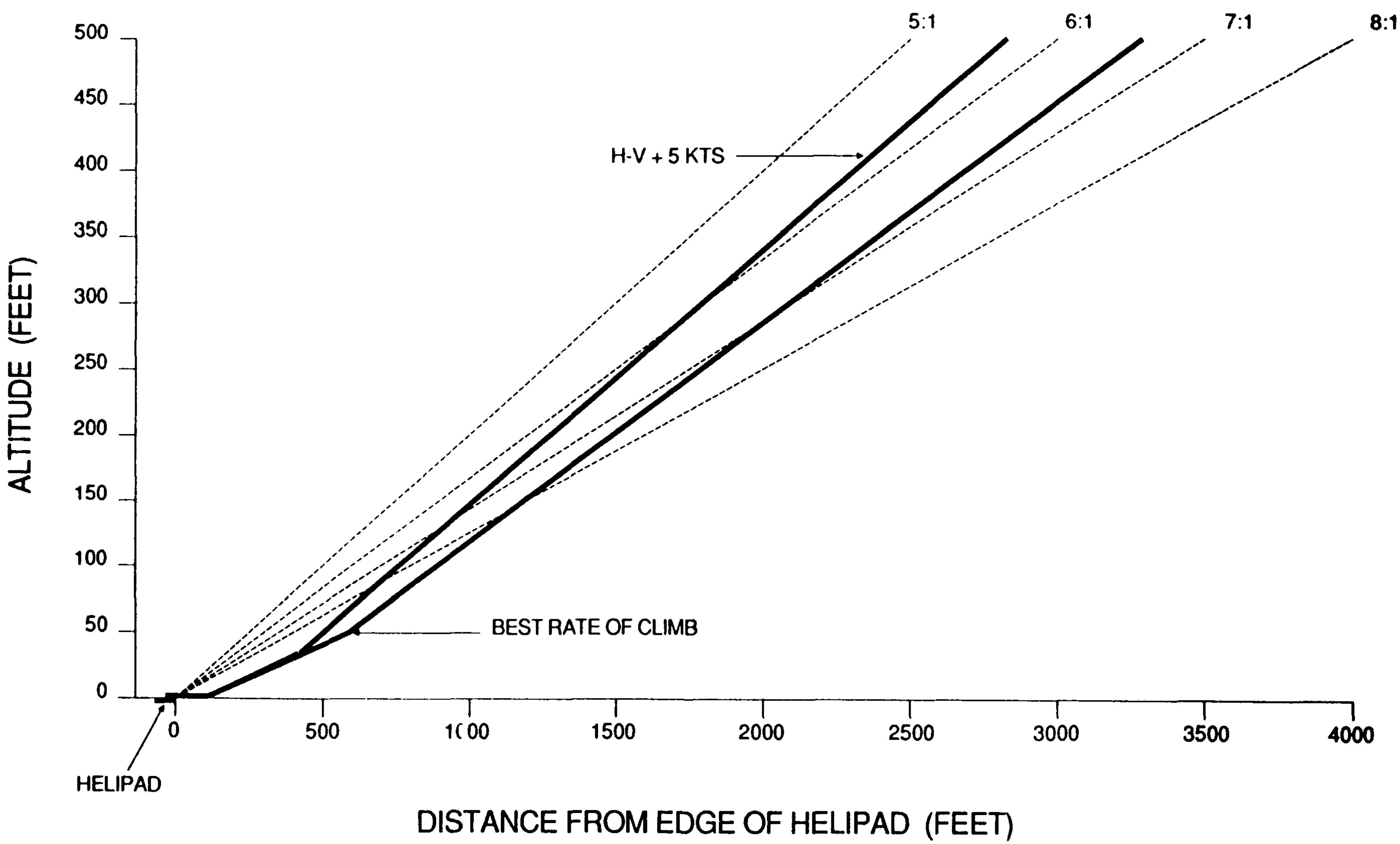
B 206B III DEPARTURE PROFILES

MAX G.W., 4000 FEET, STANDARD DAY



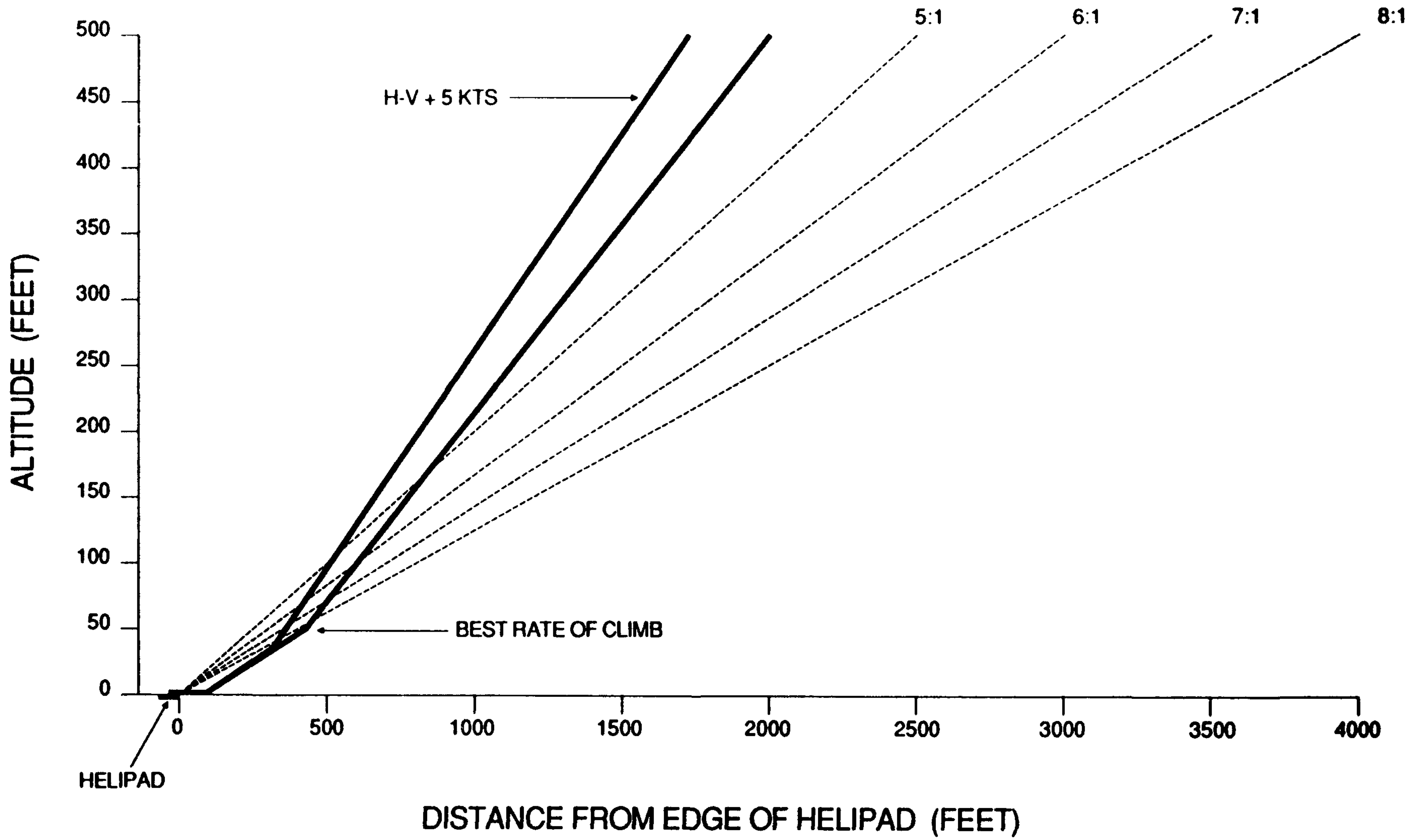
B 206B III DEPARTURE PROFILES

MAX. G.W., 4000 FEET, HOT DAY



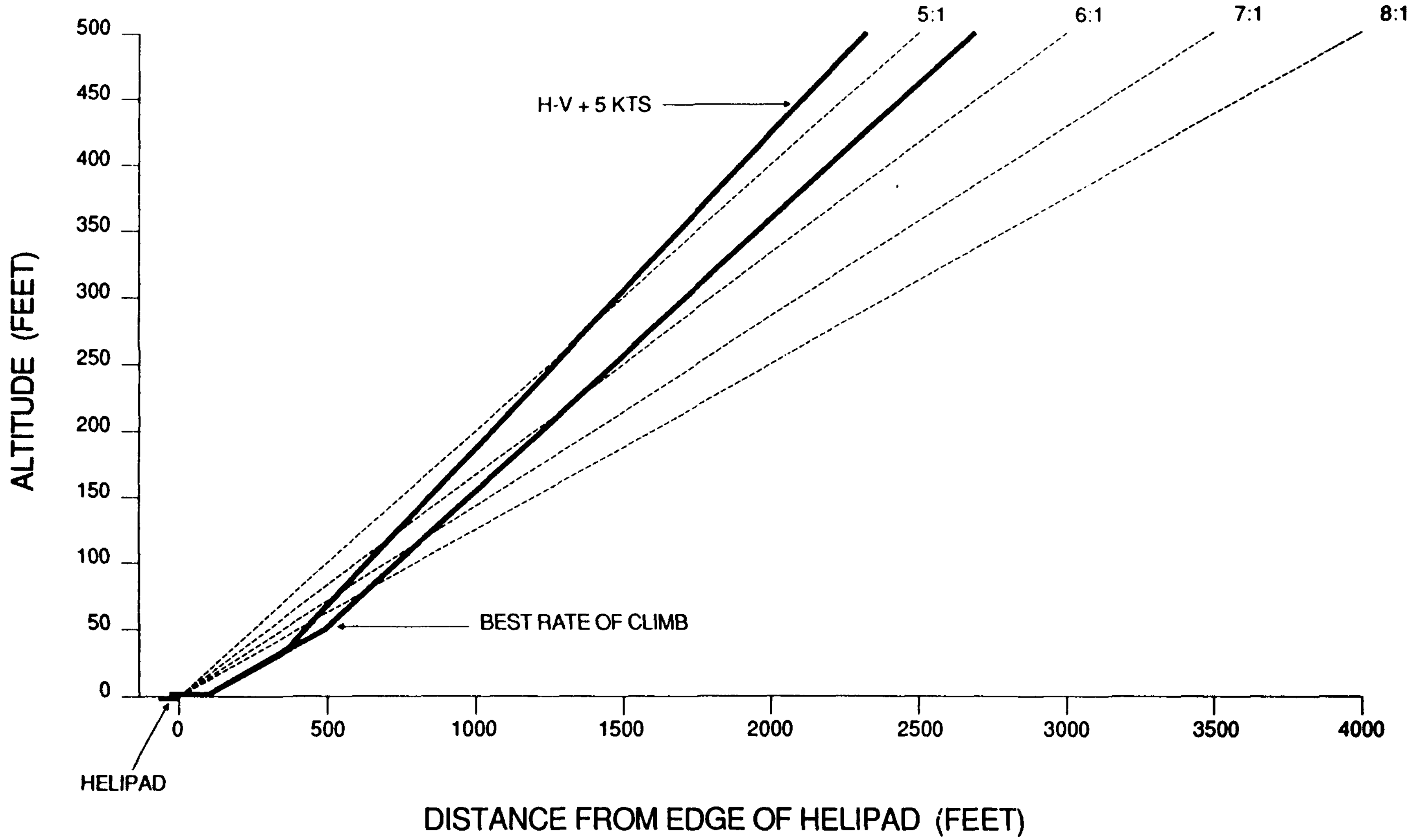
B 206B III DEPARTURE PROFILES

85% MAX. G.W., SEA LEVEL, STANDARD DAY



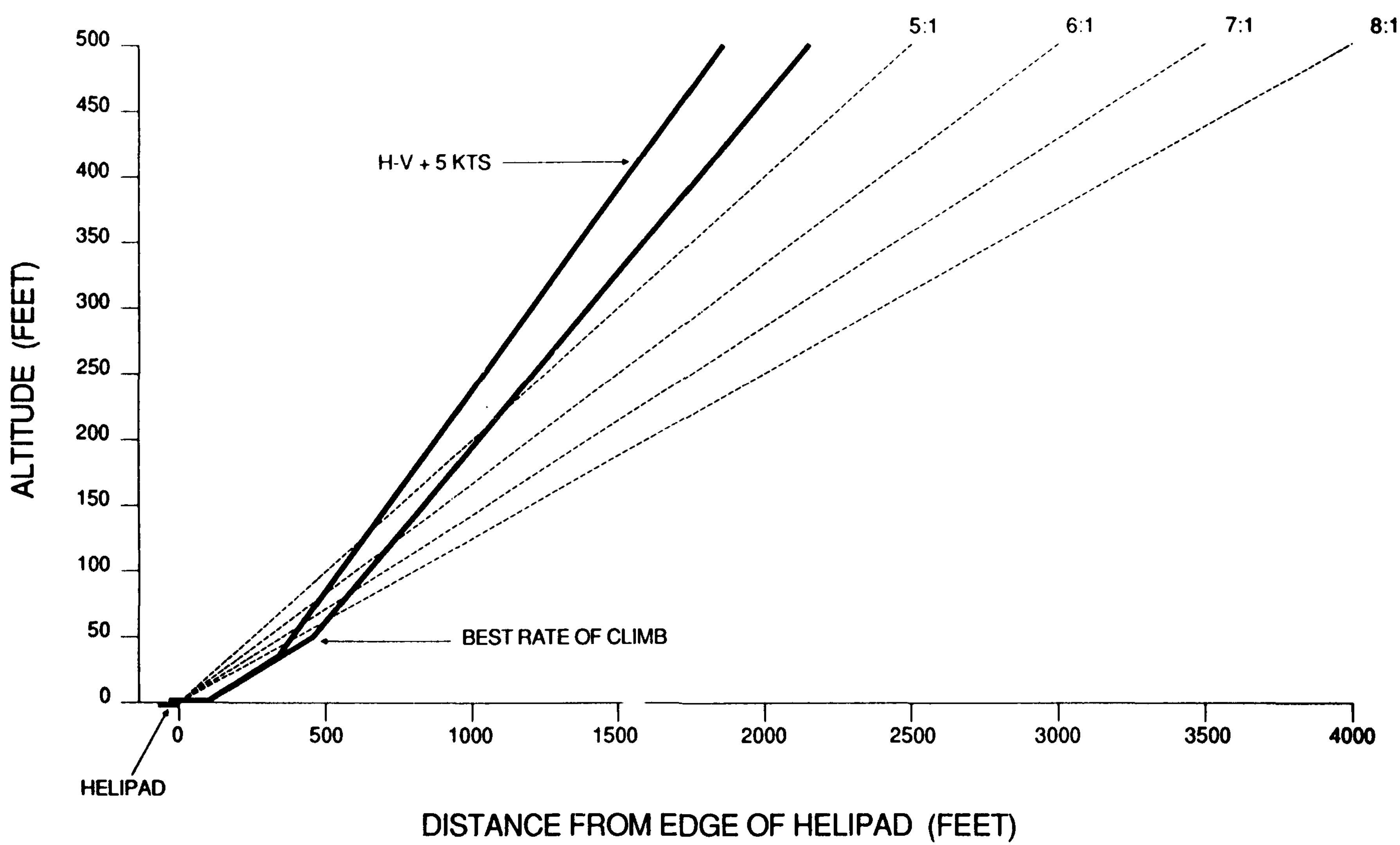
B 206B III DEPARTURE PROFILES

85% MAX. G.W., SEA LEVEL, HOT DAY



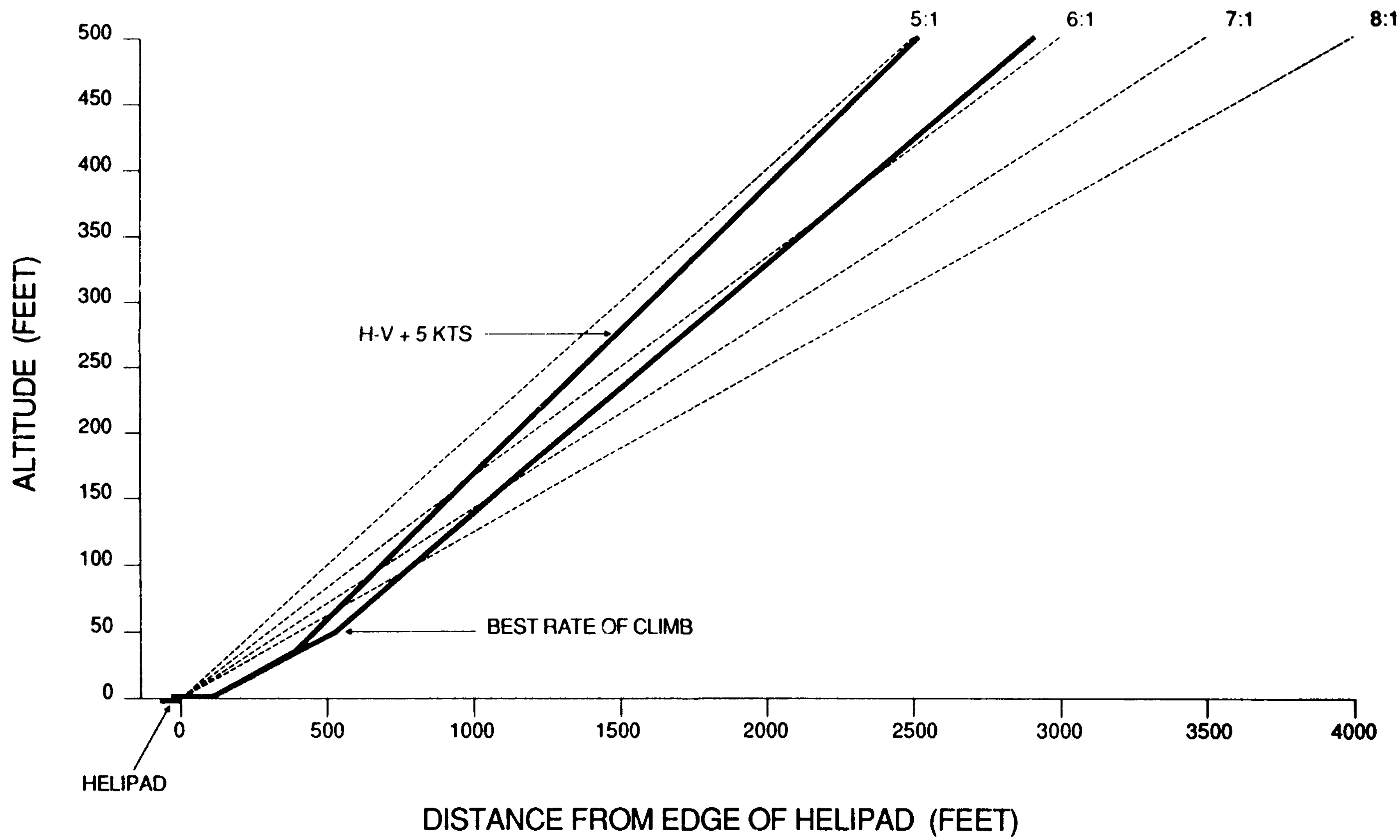
B 206B III DEPARTURE PROFILES

85% MAX. G.W., 2000 FEET, STANDARD DAY



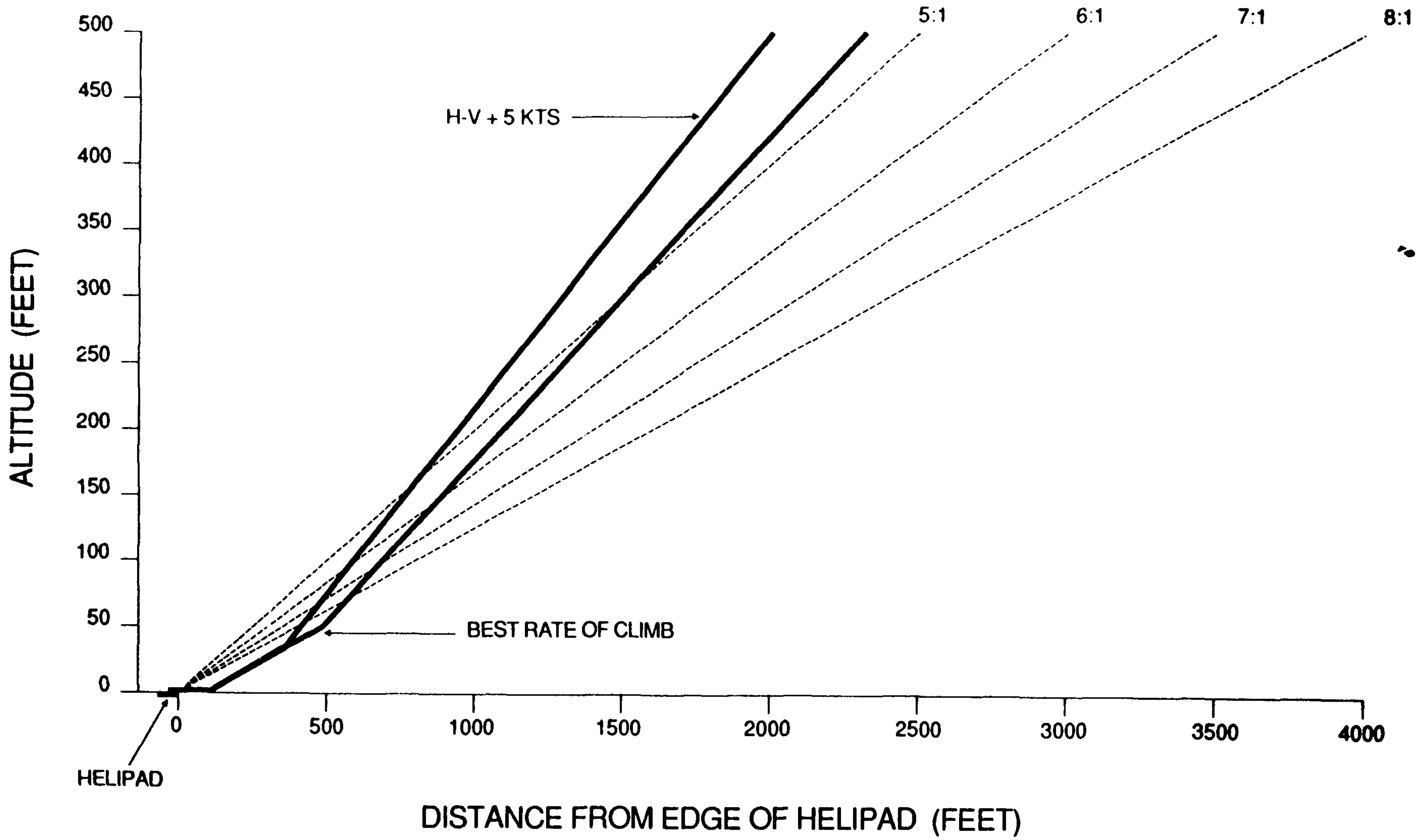
B 206B III DEPARTURE PROFILES

85% MAX. G.W., 2000 FEET, HOT DAY



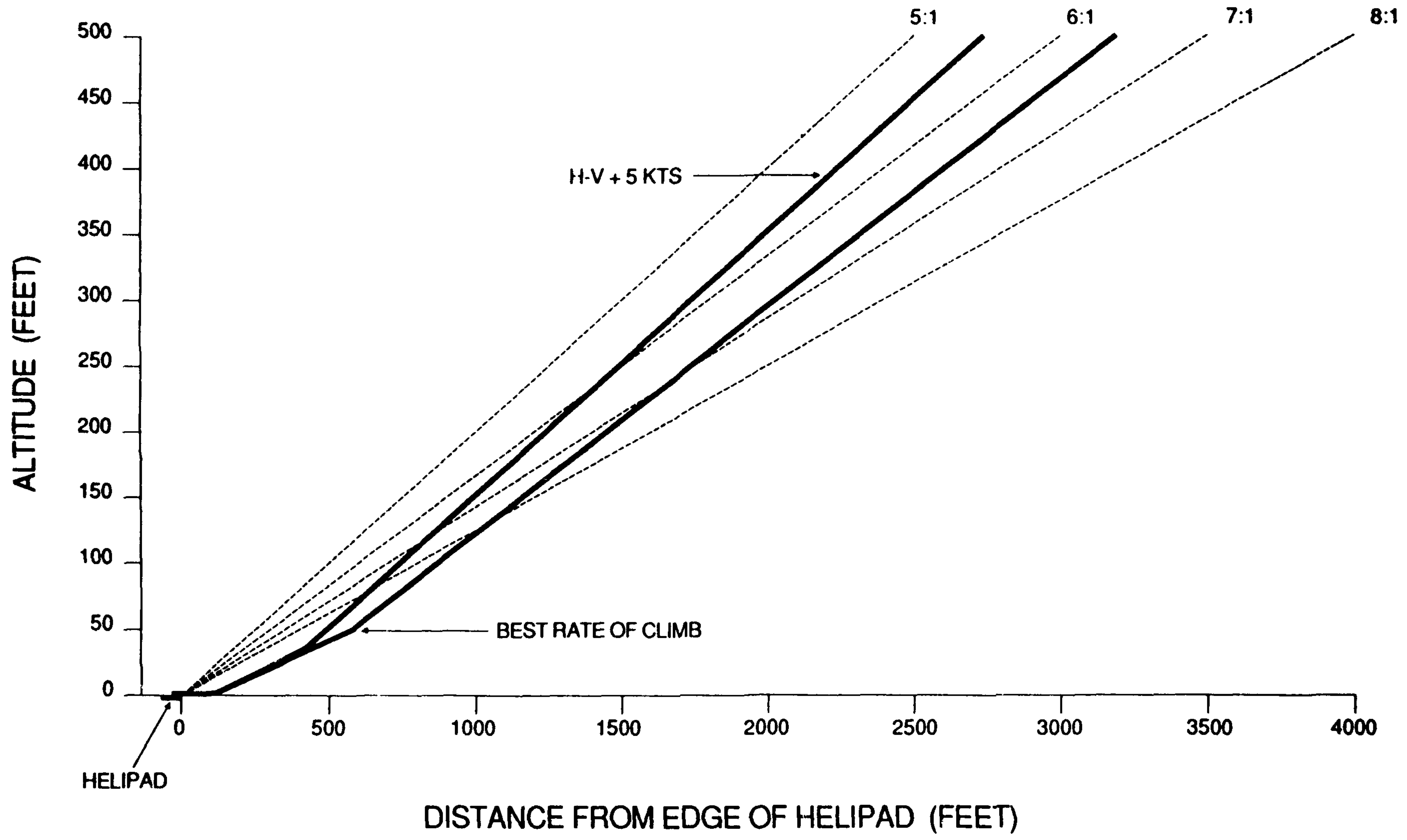
B 206B III DEPARTURE PROFILES

85% MAX. G.W., 4000 FEET, STANDARD DAY



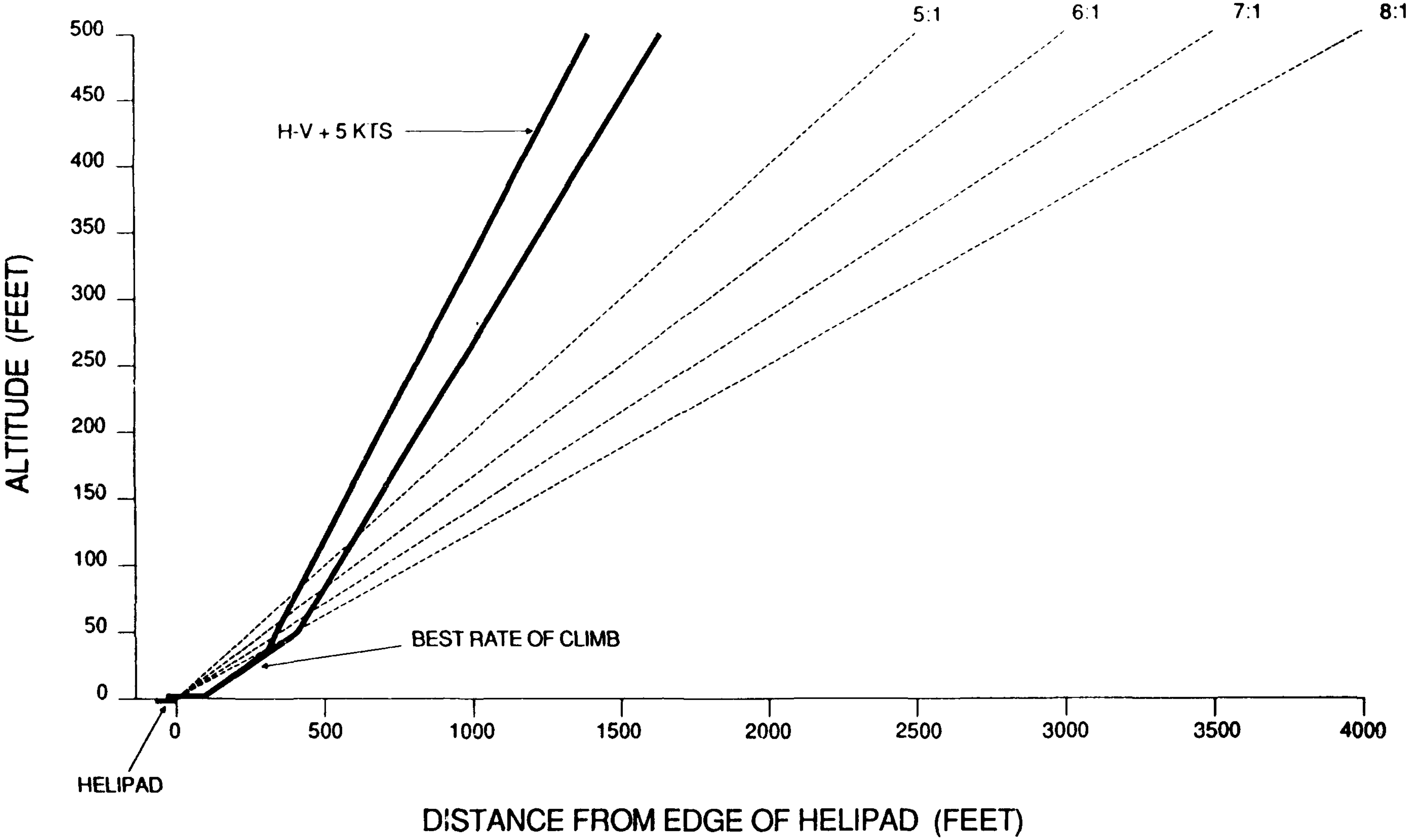
B 206B III DEPARTURE PROFILES

85% MAX. G.W., 4000 FEET, HOT DAY



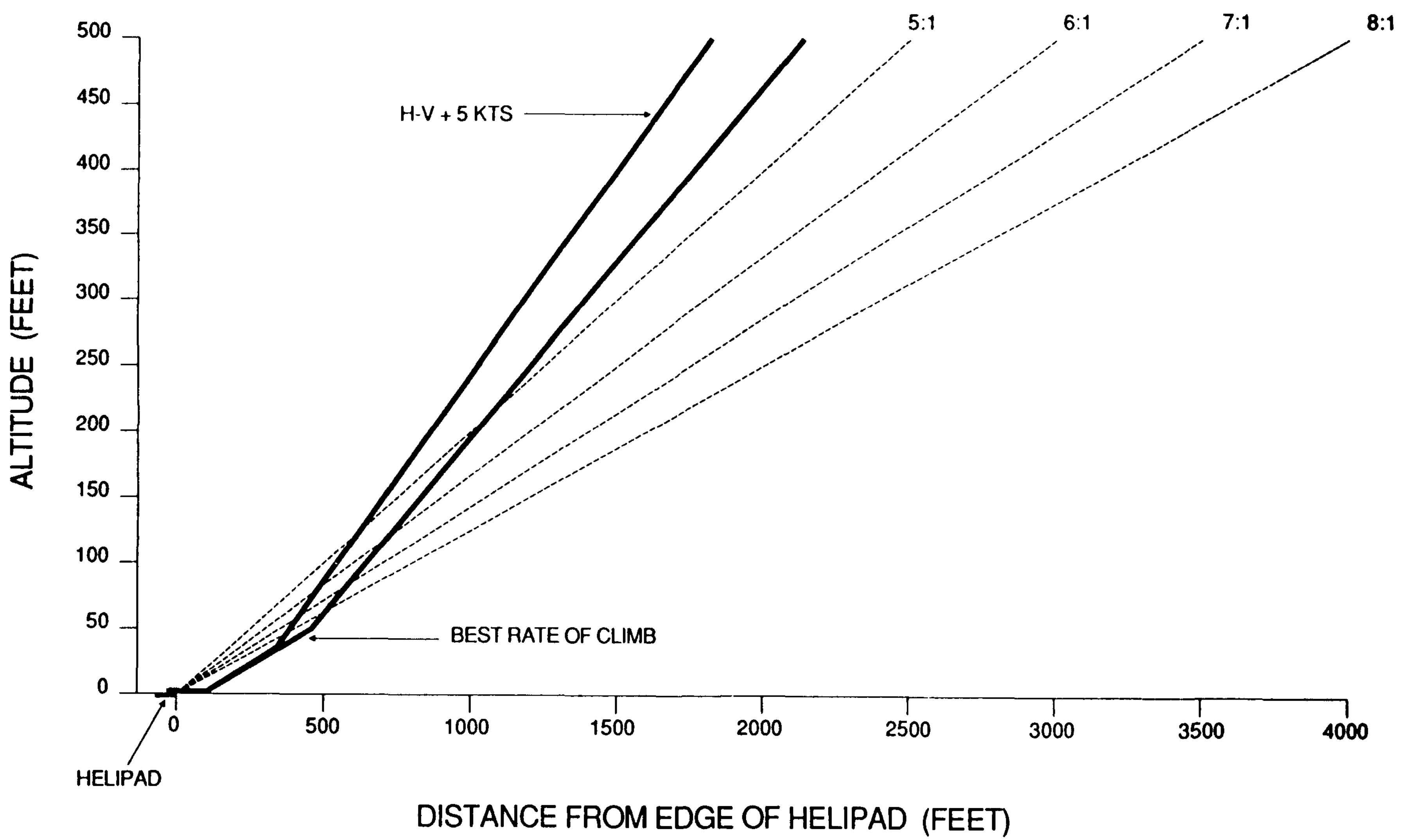
B 206B III DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL, STANDARD DAY



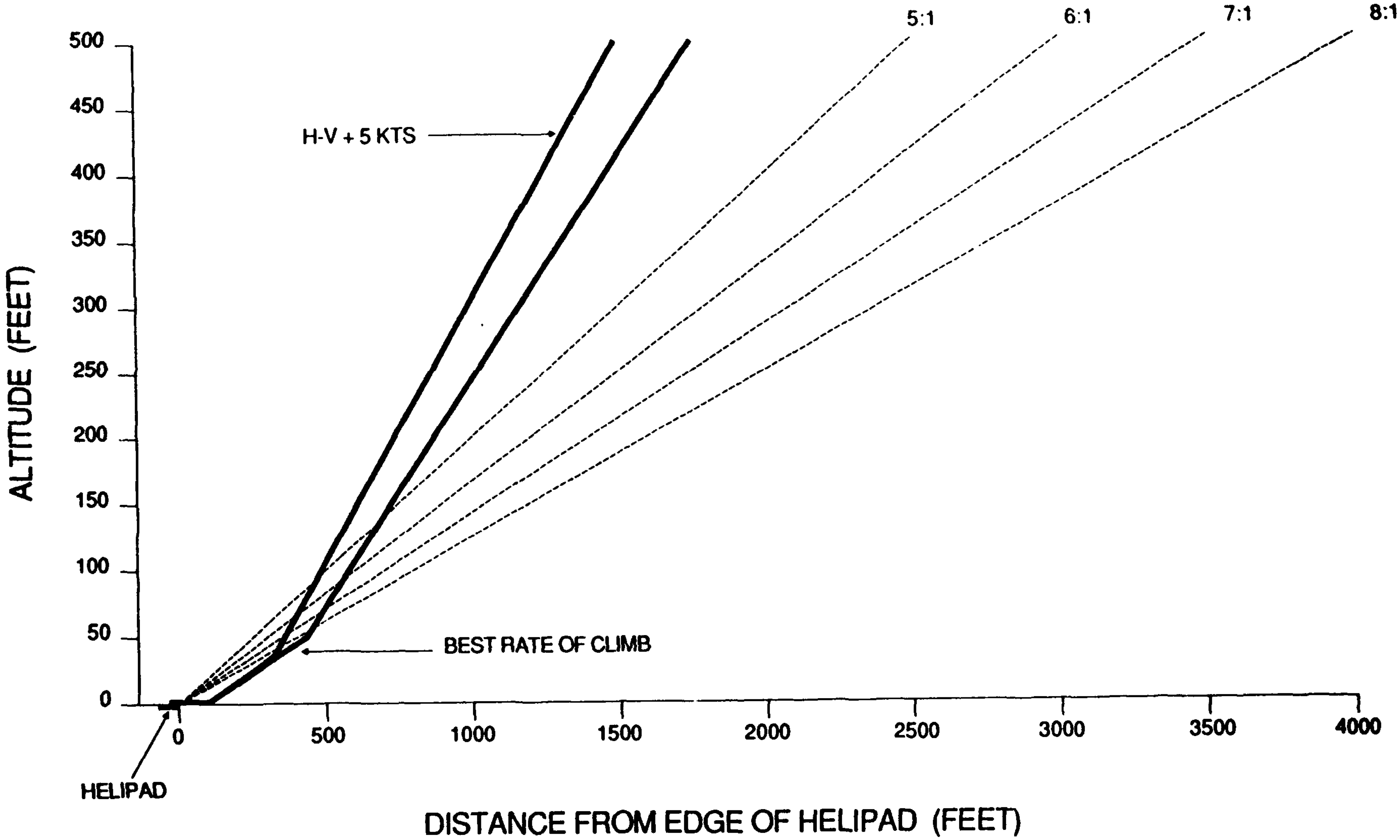
B 206B III DEPARTURE PROFILES

70% MAX. G.W., SEA LEVEL, HOT DAY



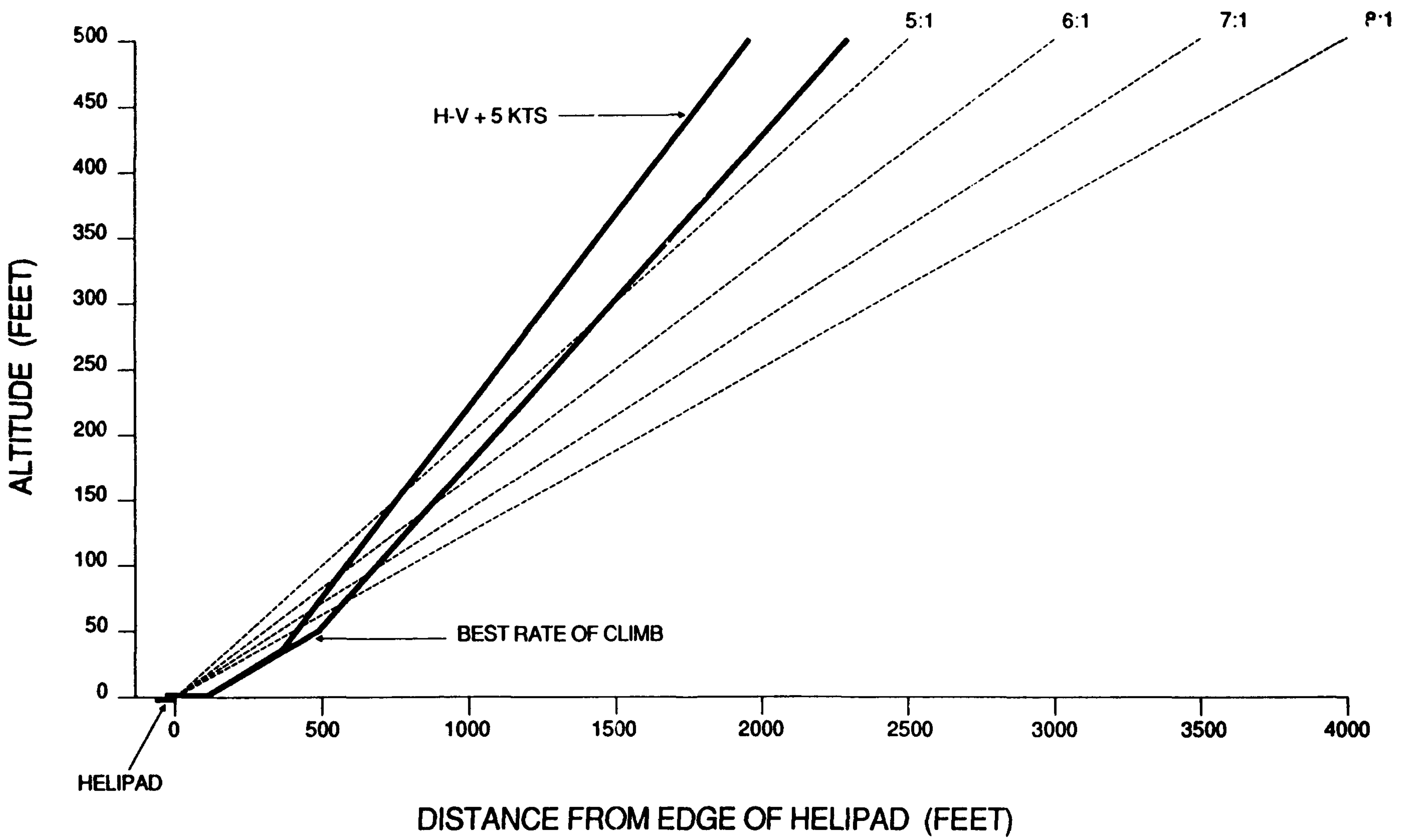
B 206B III DEPARTURE PROFILES

70% MAX. G.W., 2000 FEET, STANDARD DAY



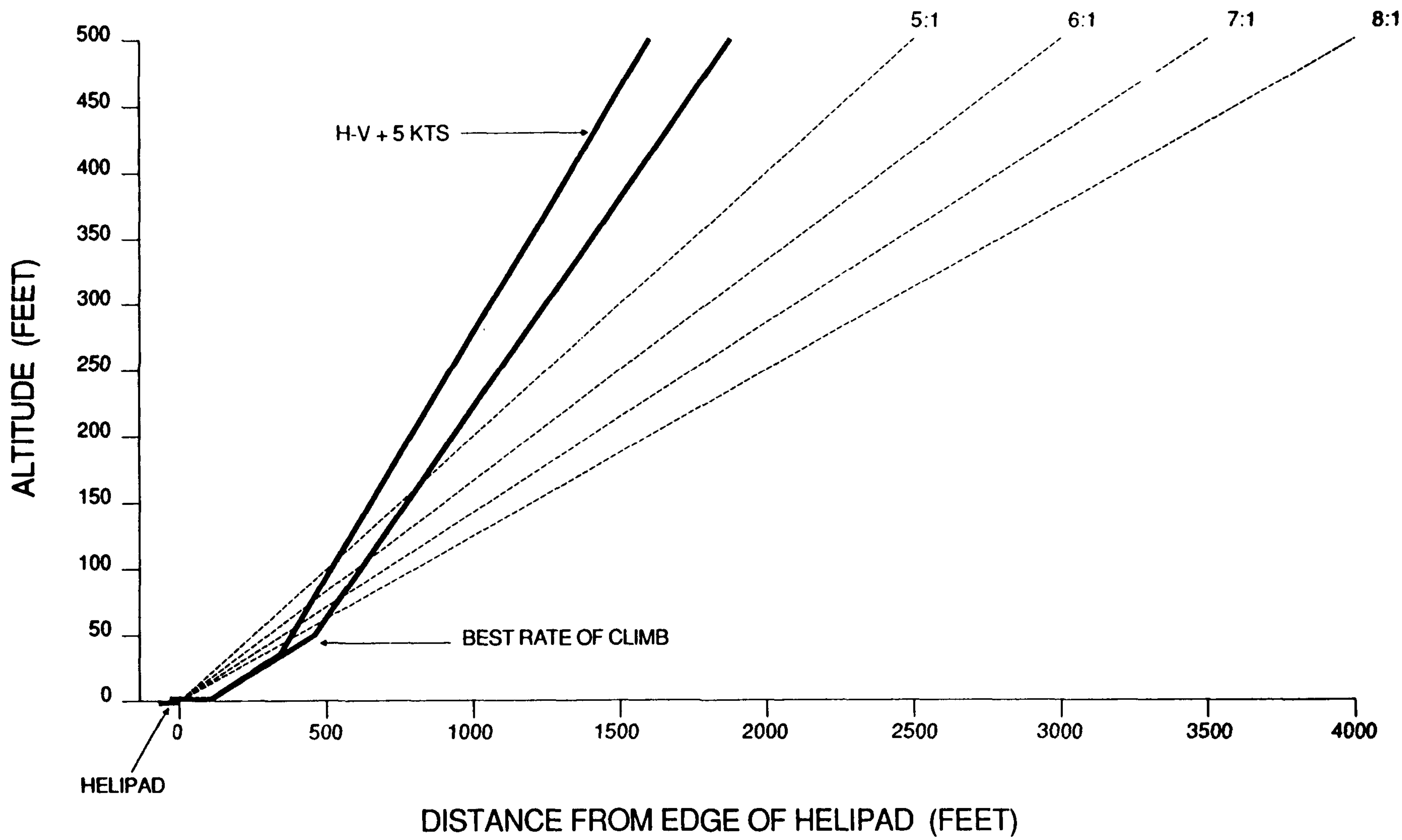
B 206B III DEPARTURE PROFILES

70% MAX. G.W., 2000 FEET, HOT DAY



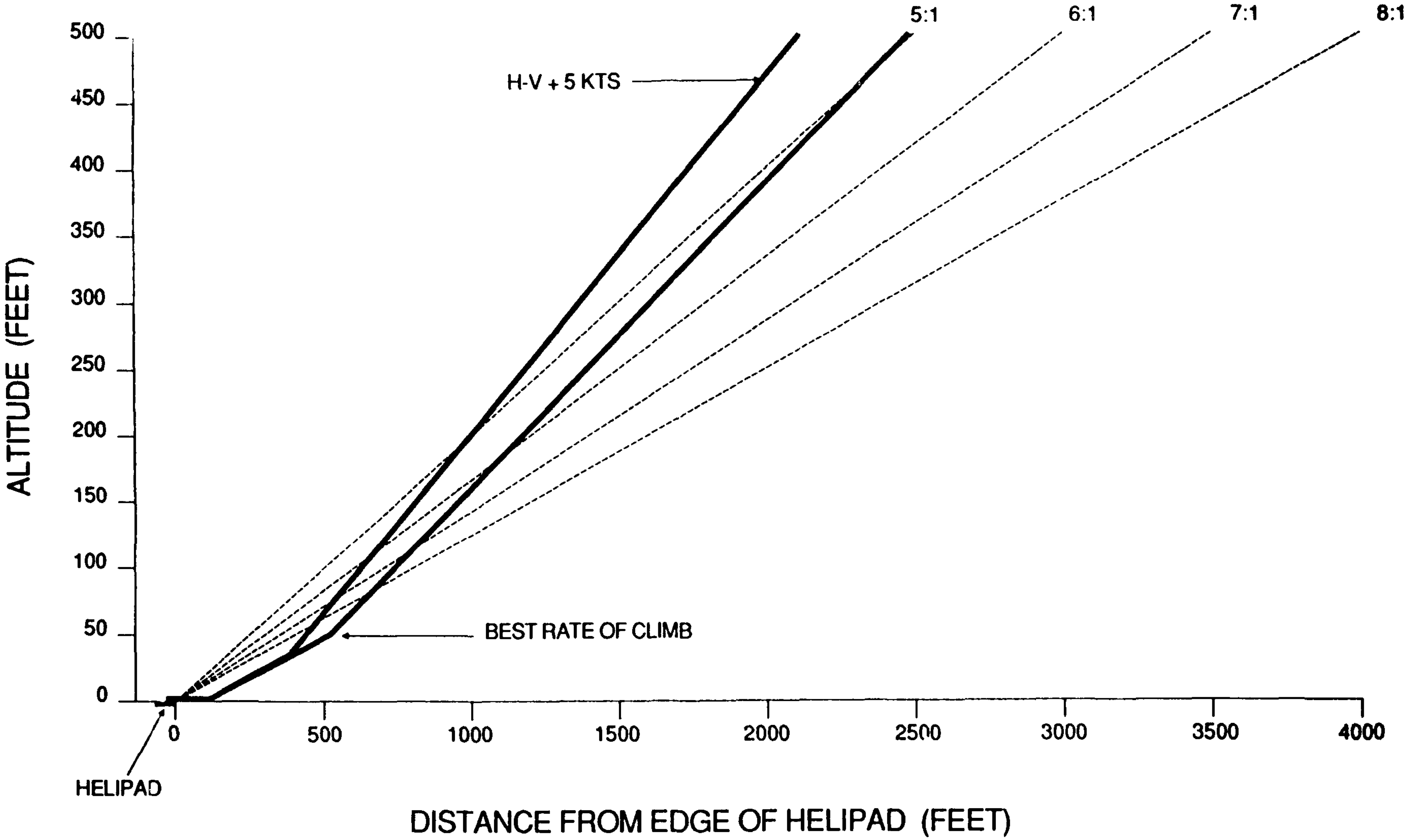
B 206B III DEPARTURE PROFILES

70% MAX. G.W., 4000 FEET, STANDARD DAY



B 206B III DEPARTURE PROFILES

70% MAX. G.W., 4000 FEET, HOT DAY



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